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Presidential Address

Notes on a Visit to the U.S.S.R. to Observe Surgical Technics and Research, June 27–July 10, 1959

PRIOR to the meeting of the International Congress of Plastic Surgery in London last summer, a group of us spent two weeks in Leningrad and Moscow on a non-official tour for the purpose of visiting hospitals to observe surgical technics and research. Our visas were secured on this basis and only after two years of fruitless effort to obtain official permission to enter medical institutions. We had written ahead to Professor A. A. Limberg in Leningrad and to the three Soviet delegates to the International Congress in Stockholm in 1955 (Professors A. V. Vishnevsky, B. A. Petrov and N. N. Blokhin in Moscow). Other American surgeons had told us that once inside Russia, doors might be opened to us with the help of Intourist and the medical attaché at the American Embassy.

Our party included four other plastic surgeons (Dr. Clifford Kiehn of Cleveland, Dr. Clarence Straatsma and Dr. Herbert Conway of New York; and Dr. Wallace Steffensen of Grand Rapids), my wife (Dr. Virginia Blocker), and my oldest son.

For all of us it was an interesting adventure. None of us claims to be an expert on politics or even the status of medicine in the U.S.S.R.; nevertheless, we thought it worthwhile to share with our colleagues the notes of our trip, our first-hand impressions and a glimpse into life in the Soviet Union today through our photographs. There has been little exchange of tourists until recently, and not until this past summer have large numbers of Americans and Western Europeans journeyed into Russia by plane, train, bus and even private automobiles. Since restrictions have been relaxed, it is hoped that there will also be unofficial travel of visitors from the Soviet Union to the United States and other countries.

In Leningrad there was much that we wished to see in the various medical institutes, but we were handicapped by a lack of prior arrangements through the Ministry of Health and the Academy of Medical Sciences in Moscow or by correspondence with individual professors ahead of time. Had we gone to the latter city first, perhaps other doors would have been opened to us; or if we had known the names of more hospitals, we might have been able to establish contacts by telephone. We had a most satisfactory visit, however, on two successive days at the Institute for Traumatology and Orthopedics with Professor Limberg and we inspected, also, at the First Leningrad Medical Institute the service of Professor F. G. Uglov, a thoracic and cardiac surgeon whom I had met briefly in Houston several months before when he was on a tour sponsored by the University Surgeons. In addition, we went to the University of Leningrad one afternoon, where we met the research staff in biochemistry and the Professor of Zoology and had a hurried view, in passing, of the magnificient library of antique books.

In Moscow we learned that it is not possible

for all doctors coming to the Soviet Union to be taken on tours through hospitals simply because of difficulties in arrangements and the burden of visitors on the directors and staff. Even to enter one of the universities, permission must be obtained through the Director (the Embassies must also be authorized by the Ministry of Education after approval from the Foreign Ministry); and, in the absence of directories or even names on doors, it may be difficult to find the professor or even the department desired. The hospitals and medical institutes do not allow the relatives of patients to enter the wards, and there is no way of wandering in for a casual look around. Authorized visitors such as our group appeared to disrupt the day's activities considerably.

We had an excellent scientific Intourist guide in Leningrad. Our two women guides in Moscow, however, confessed that they had never been in a hospital before. For them it was a terrifying experience to go directly to the operating room and be confronted with a child undergoing thoracic or abdominal surgery, to see patients with severe facial injuries and to have the equipment for the processing of cadaver blood demonstrated to them. Needless to say, they had only meager medical vocabularies although they spoke English very well and were of great help aside from our hospital excursions.

The institutes which we visited in Moscow were as follows: the Institute for Experimental Surgical Apparatus and Instruments; the Sklifosovsky Institute; the Vishnevsky Institute for Surgical Research; the Institute for Experimental Pathology and Therapy of Cancer; and the Central Institute for Orthopedics and Traumatology. We saw, also, the buildings for the Institute for Experimental Medical Apparatus. All these facilities are prestige establishments. In each we received a warm welcome, and on three occasions we were entertained at lunch with fresh caviar and other delicacies and with appropriate speeches and toasts to mutual goodwill and to free exchange of scientific knowledge between our countries.

At the Fourth of July reception given by American Ambassador and Mrs. Thompson—an event for all of Moscow, judging by the spectators outside for blocks, and the well dressed company of 1,200 or 1,300 in the house and gardens—we met the Minister of Health, S. V. Kurashov, who is a member of the Council of Ministers appointed by the Supreme Soviet of the U.S.S.R. Under his jurisdiction are all the health and medical services at the various levels of government, even including sports and physical culture, nursery schools, rest homes for workers on vacation, summer camps for children, and the manufacture and distribution of medical supplies and drugs.

The medical teaching institutes, which were separated from the universities in 1929, exist on two levels. One group, of which there are about seventy, correspond to our medical schools with the exception that graduates receive a physician's certificate rather than a degree after two years of preclinical and four years of clinical training. They require entrance examinations and accept students following the completion of the ten-year secondary school education (beginning at the age of seven). Certain nonmedical subjects are taken, e.g., political science, philosophy and economy, but apparently not the broader courses which our college students take along with the prescribed premedical curriculum. The so-called Medium Medical Schools provide for the training of nurses, midwives, technicians and feldschers (junior doctors), who enter from the secondary schools (some have only seven years instead of ten) and study for two to four years, depending on the course of instruction.

Each medical school is made up of one or more faculties in such specialties as therapeutics, pediatrics, hygiene, pharmacology and stomatology, with students divided among the various categories. The courses are identical for the first two years, and public health is included in the course of study for all. During medical school, students may specialize in pediatrics, public health and stomatology. Other specialists require postgraduate training of one type or another. We were interested to learn that almost three-fourths of the doctors have specialty rating and that general practice, as such, is carried on in the rural areas chiefly or by feldschers at the dispensary level. Preceptorships of one month each are arranged during the last three years of study in medical school. Apparently some differences exist in the level of training in the various parts of the Soviet Union just as there are differences in secondary education. Instruction is given only in the Russian language during the clinical courses, but lectures are also given in the regional dialects during the preclinical years.

Upon completion of medical school training, physicians are assigned for three years of practice or in exceptional cases for postgraduate work. Specialty training is available in the form of three-month refresher courses followed by work in a particular field or, more rarely, by assignment to the *Ordinatura* for three years, which corresponds more closely to our residency system.

The *Aspirancy* program for research and investigative work leads first, usually after five years, to preparation for a degree of Candidate of Medical Sciences, which involves presenting and defending a thesis. Senior assistants, who are chosen by competitive examination may prepare a second thesis (after a period of three to five years), and work toward a degree of Doctor of Medical Science, which qualifies them to serve in time as heads of departments in medical research institutes, professors and members of the U.S.S.R. Academy of Medical Sciences and the various Republic Academies of Sciences. Degrees are recommended by the medical institute faculties but awarded by a Commission of Higher Degrees of the Department of Education.

The Academy of Medical Sciences, which contains departments for chemical sciences, hygiene and medical-biological sciences, supervises the work of the various research institutes and assigns to them projects as outlined under a long range program of planning. The Academy is composed of 120 corresponding associate members and 100 active members who meet annually to present papers and to propose names for vacancies as they occur. Officers are elected to serve a three-year term. We were privileged to meet at dinner one evening A. N. Bakulev, then President of the Academy, and his wife. Members of the Academy enjoy considerable prestige and receive much higher pay than other professors.

Aside from the chiefs of services in the various institutes and the directors, we met very few doctors who were not women. The official estimate is now approximately 76 per cent, but male surgeons have a much wider reputation, it would appear, even though many of the women may have equal training and technical skill. We were interested to note that the official Russian representative to the International Congress in London was a woman, Dr. E. V. Gruzhdova. We met a number of well qualified women surgeons, among them Dr. Antonina Titova and Dr. Alla Limberg in Leningrad; Dr. Vishnevsky's assistant, who has performed more than 100 heart operations successfully; Dr. M. T. Panova, an orthopedist; and Dr. Blokhin's wife, a surgeon in the Oncologic Institute.

We had no opportunity to assess the standards of care at the general level of medical or surgical practice. Undoubtedly a great deal has been accomplished in a relatively short period from the public health standpoint, particularly in the control of major communicable diseases and general health education, but much yet remains to be done. At the present time there is a widespread safety campaign with regard to traffic accidents, burns and the like, which is most commendable. But, judging from the institutes which we visited, there is still an insufficient budget allocated to the basic adjuncts of routine hospital care.

No effort has been made up to the present, as far as we could tell, to display new hospitals and medical institutes for exhibition purposes, although some new construction is being carried out. Almost every hospital which we saw was located behind walls with a narrow entrance gateway. All were rather outmoded with extremely poor lighting and plumbing facilities, much in the style of our original John Sealy Hospital in Galveston, which was built in the 1890's. There were large grounds reminiscent of our state mental institutions with benches for patients and their friends and relatives. Many of the laboratories have been set up in makeshift quarters, and the wards all appeared to be overcrowded, sometimes with beds touching. Only in Professor Uglov's hospital did we see individual oxygen connections from a central system. Bed linens and gowns furnished to patients appeared to be of poor quality. No infusion apparatus was noted in any wards which we visited, and we saw no oxygen tents. Some patients had special attendants, and there was abundant personnel everywhere, but no clerks or other helpers to assist with patient records. Children were noted in some instances to be in wards with adults. Ambulatory patients came to meals at tables in special dining rooms or anterooms adjacent to the wards. These were furnished usually with round tables, ferns, white curtains with cutwork embroidery and the universal photographs of Lenin and Stalin.

There was considerable variation in equipment in the various institutes. Professor

Limberg, for example, had no dermatome and only old models of the chondrojet, although we saw the latest models of these at the Institute for Surgical Apparatus and Instruments. One would assume, therefore, that there is a difference in "appropriations" according to government priority or other criteria. Dr. Uglov had a color television camera in his operating suite and showed us a room for viewing which had a number of receiving sets. In no hospital did we observe modern dressings; there were no bandaids, adhesive, elastic bandage, fluff gauze or any type of ready-prepared dressing. This was in marked contrast to the elaborate mechanical devices for treatment of complicated fractures; intramedullary pins of hemoglobin, compressed plasma, or casein and the well publicized stapling devices. Moderately fine suture material, mostly catgut and nylon for the skin, was used for routine work. Vishnevsky had a Bovie unit for electrocoagulation. We saw no flashlights, headlamps or gooseneck lamps for examination of patients.

We were interested to note that standards of sterility and hygiene vary considerably from ours. The women surgeons in Leningrad wore no gloves while operating, nor did Vishnevsky, although they rinsed their hands frequently in antiseptic solutions and kept them covered with gauze when not busy. Street clothes were worn by everyone except Professor Petrov, but all personnel, including visitors, put on a clean gown and cap over ordinary clothing on entering the hospital. Scrub gowns are worn over these, and sometimes leggings are used to protect stockings or trousers. Less attention is paid to the ritual of draping patients, and there are numerous "breaks" in technic according to our standards, e.g., the surgeons wipe their own brows with their sleeves and occasionally turn their backs on the table. Inquiry was made in several institutions with regard to the staphylococcus problem; we were told that it does exist but that it is not as prevalent as in our country because of (1) less routine administration of antibiotics to the general population; (2) control of visitors to patients inside the hospital; and (3) less refinement of technics with perhaps greater natural immunity.

We were all anxious to evaluate the status of plastic surgery in Russia. It is not organized as in our country but has a close alliance with orthopedics. There is more emphasis on maxillofacial work, as in Germany, and the two institutes of orthopedics and traumatology which we visited appeared to be concerned primarily with definitive procedures rather than primary treatment. Patients with emergency fractures and lacerations come to the Sklifosovsky Institute and to industrial hospitals in the city and presumably are seen first at one of the numerous first-aid stations or "points" in rural areas which are staffed by feldschers.

Only a limited number of patients with burns were seen, about thirty or forty who were hospitalized for reconstructive procedures, and perhaps seven with acute or subacute burns, one on Professor Petrov's service and the remainder at the Orthopedics and Traumatology Institute in Moscow. With regard to fluid therapy, whole blood is used—cadaver blood at the Sklifosovsky Institute with some use of bovine plasma injections—and the Evans formula serves as a general guide. Occlusive dressing technics were being employed for local therapy, over a yellow antibiotic ointment at the Sklifosovsky Institute. Dr. Priorov mentioned the use of bovine peritoneum, moistened in saline, as dressing for acute burns, and gave us small samples.

Before going to the Soviet Union we were of the impression that many surgeons preferred local anesthesia to general anesthesia. This we found not to be true. Trained anesthesiologists are scarce, but wherever there is a physician skilled in endotracheal intubation the surgeons used inhalation anesthesia. They employed local and regional technics very well about the face, however, and we noted that Vishnevsky made repeated injections of novocaine solution into the wound during exposure for heart surgery. Hypothermia is employed in some institutions. A child undergoing the operation for tetralogy of Fallot had been placed in a tub of water containing dry ice which was adjacent to the operating room. The patient's temperature was reported as being 32°C. throughout the procedure.

Although we had an opportunity to visit one of the institutes for blood transfusion research in Moscow, we were unable to because our schedule was too busy toward the end of our stay. In the Sklifosovsky Institute we saw the laboratory for collecting and processing of cadaver blood, which has been used here for thirty years [*1,2*]. Professor Petrov is most enthusiastic about cadaver or "liquid" blood,

FIG. 1. Women surgeons at work (Dr. Antonina Titova and Dr. Alla Limberg, Institute for Traumatology and Orthopedics, Leningrad).

as he calls it; other surgeons seem reluctant to use it or perhaps have had little experience with it since an insufficient quantity is collected for the total needs of the one institute. All persons who die suddenly without obvious disease or open trauma are brought immediately to the Institute and placed on an operating table in the Trendelenburg position. Blood is collected from the neck by gravity with plastic catheters into both ends of the left jugular vein. From 2 to 4 L. are received into graduated flasks of small diameter and about 150 to 200 cc. capacity. No citrate or other anticoagulant is employed. Clots are removed by fibrinolytic action, and it is Petrov's opinion that this blood is superior to fresh blood from the standpoint of reactions. It is typed and refrigerated for five days before use, during which time the patient's tissues obtained from autopsy are carefully examined and a series of tests performed, e.g., Wasserman, culture and serum bilibrubin. If during this time a reason is found for not using the blood, it is discarded; otherwise, it is kept for as long as four to six weeks. It has been used after longer storage time but only when antibiotics and dextrose have been added at the time of collection of the blood. About 150 L. per month are collected in this way for use in the accident room and in surgery.

Professor Uglov demonstrated to us an apparatus for the use of placental blood in heart surgery cases. He believed that such blood was superior because of the presence of hormones which helped to prevent shock and because of the greater concentration of gamma globulins. It had a preservative and an anticogulant added. No surgeon whom we saw in Moscow appeared to be using placental blood or could give us more information about it.

From our observations in the operating rooms, as well as conversation with a number of surgeons, we do not believe that patients are given as large amounts of replacement solutions as are commonly employed in this country. Dr. Vishnevsky said that there was a Russian dextran but that his own experience was with the Swedish solution.

Our notes with respect to the individual institutes are rather detailed. At the Institute for Orthopedics and Traumatology in Leningrad we were much impressed with the variety of diseases and the excellence of technic on maxillofacial patients. A number of patients with cleft palate were seen. It is Professor Limberg's policy to wait until the child is ten to twelve years of age for surgery, using local anesthesia, but he inserts an obturator as soon after birth as possible. Following examination of patients we went with him to a small conference room where he discussed the mathematics of skin flaps, the subject of his textbook published about thirty years ago. He is truly one of the great pioneers of modern plastic surgery technics. The following day we re-

FIG. 2. Surgical ward on Cardio-thoracic Service of Professor F. G. Uglov, First Leningrad Medical Institute.

turned to observe three cases of cartilage implants using the chondrojet, and a skin graft behind the ear for reconstruction of the upper half after loss from a severe gasoline burn. These were performed by Dr. Antonina Titova, Dr. Alla Limberg (Professor Limberg's daughter) and Dr. Natalie Harchuk. (Fig. 1.)

At the First Leningrad Medical Institute, Professor Uglov took us on a tour of his thoracic and cardiovascular surgical service and showed us through the operating rooms and the research laboratories. (Fig. 2.) However, we had only a cursory view of the wards and saw no demonstration of patients and no actual work in progress. He told us that his staff included thirty assistants and twenty postgraduate students.

The Institute for Experimental Surgical Apparatus and Instruments is a unique research unit under the direction of Dr. M. G. Ananjev, for the design and manufacture of surgical instruments and for experimental animal surgery. We were welcomed most heartily by both the engineering and medical department heads and spent approximately three hours inspecting the various facilities, taking photographs, examining equipment, watching an experimental kidney transplant into the neck of a dog and seeing films of the instruments in use. Demonstrations were conducted by Drs. Ananjev, L. Gritsman, E. Gorbovitsky, E. Teplitsky, and A. G. Lapchinsky. Professor Lapchinsky is in charge of experimental surgery and has devised the perfusion apparatus which enables him to reattach successfully an amputated dog's hind limb after twenty-four hours. He is also well known for his work on kidney transplantation in dogs. The various types of stapling devices for blood vessels were seen and also those for the lung, the bronchus, the stomach and the intestine. We were shown a heart-lung machine; a pace maker; pressed casein, plasma and hemoglobin "nails" for the fixation of fractures; bone glue; a stereoencephalotome; and two types of electronarcosis machines in addition to a number of standard surgical instruments. The narcosis machines have recently been described in the *New York Times* (July 17, 1959) and in *Newsweek* about the same time in connection with the contract of the Rand Company to manufacture these and other devices in the United States. We saw none in use but were told that they were used in tranquillizing mental patients and during the convalescent period in patients with burns.

Following our meeting with Professor and Mrs. Petrov two days previously at the American Embassy party, it was evident that careful preparations had been made at the Sklifosovsky Institute, the Emergency Hospital of Moscow, to show us what we wished most to see. When we arrived, we were taken by Dr. Mikhail Tarasov, the Director, to a seminar

FIG. 3. Administration of cadaver blood transfusion to patient undergoing first-stage surgery for reconstruction of esophagus, Sklifosovsky Institute, Moscow (Dr. Clifford Kiehn and author, *right;* Dr. B. A. Petrov, *center front*).

room where the entire staff of this large institute meets each morning to review the events of the previous twenty-four hours. The institute was built approximately 150 years ago and has steadily grown to include now 850 surgical beds, 100 in gynecology, and 165 for general therapy. The staff on duty at all times includes ten surgeons, two internists, two radiologists, two laboratory technicians and two gynecologists. Over 1,000 patients are seen each day. The teaching program includes 150 sixth year medical students, 80 three-year postgraduate students, and 30 physicians there for three-months' specialty training. We were next taken to the operating amphitheater where Professor Petrov performed the first stage of construction of an artificial esophagus by bringing up a loop of colon retrosternally into the neck, using blunt dissection by dilators resembling large spoons. Inhalation ether-oxygen anesthesia was used following the initial administration of pentothal. We were all impressed with Dr. Petrov's brilliant technic, with his speed and his delicacy in handling the tissues. We noted that he had a most superior instrument nurse and that all personnel in the operating room wore well fitting gloves. During the procedure the patient received about 400 cc. of cadaver blood in addition to an equal amount of electrolyte solution. (Fig. 3.)

Following the operation, the various stapling devices were demonstrated to us on autopsy specimens as well as the small tantalum rings which are used in surgery of the great vessels.

On our arrival at the Vishnevsky Institute for Surgical Research, which was founded by the father of the present chief surgeon, we went directly to Professor Vishnevsky's office and were ushered into the operating room to observe a patient with tetralogy of Fallot. Dr. Vishnevsky worked with dispatch with three women surgeons as assistants, two instrument nurses, two circulating nurses and five instrument watchers in his retinue. An ear oximeter was employed, an electroencephalograph and a vector cardio-oscilloscope. A preserved homotransplant was inserted from the subclavian to the pulmonary artery (end-to-side), using the thin tantalum rings which we had seen demonstrated on the previous day. After surgery, we went to see some films demonstrating the use of stapling devices.

Our day at the Institute of Experimental Pathology and Therapy of Cancer proved most interesting with Dr. Natalie Perevodchikova, Dr. Blokhin's assistant, serving as interpreter and coordinating the various experimental aspects of the work with the clinical research in progress. We were first introduced to the surgical staff, which included Dr. Blokhin's wife, and were shown slides of patients treated with various types of local and systemic

anticarcinogenic agents alone and in combination with surgery. Following this demonstration, the sixty patients who were carefully selected for this research unit were seen; among these were cases of leukemia, Hodgkin's disease, basal and squamous cell carcinomas of the skin, bone tumors and abdominal malignancies, Experience with dopan, sarcolysin, and omain as well as with alkalating agents and hormones was discussed.

The staff of the institute included about fifty workers, and all experimental research was being carried out with human malignancies according to a definite protocol outlined by the Academy of Medical Sciences. In the laboratories we visited first with Professor D. A. Timofeevsky, in charge of tissue culture and electron microscopy, whose reputation is well known; next, with Professor Berlin, the experimental chemist, and with Professor Majevsky, who outlined the mode of action of various antitumor drugs. After a conference with Professor Larionov, who demonstrated experimental human tumors in lemmings and in rats, we met with Dr. Konoplev, who has just completed some remarkable work with regard to the effect of hormones on production of malignancies (carcinoma of the prostate) in male rats.

Arrangements were made for a visit on our last day in Moscow, by Mr. Mikhail Bruk of the Soviet Ministry of Health, to the Central Institute of Traumatology and Orthopedics, a 400-bed hospital with ten department heads. The director, Professor N. N. Priorov, greeted us in his office and introduced his staff, who showed us roentgenograms of over 100 clinical cases in the various departments. We met Professor Nechaeff, the chief surgeon, Professor F. M. Hitrov, who appears to have had more experience with total reconstruction of the nose than any other surgeon in the world, Professor M. T. Panova, a woman, Professor A. V. Kaplan, Professor O. T. Mamaliev and Professor Maxim Michelman. Dr. Hitrov, who is in charge of maxillofacial surgery, demonstrated a large series of patients with most extensive disease of the head and neck. The others, all orthopedic surgeons, have large series of patients with complicated fractures requiring bone grafts, cross leg flaps and tubed pedicle flaps. We saw a number of patients who had had transplantation of homografts of the head and upper shaft of the femur with the longest follow-up period about two years. Professor Michelman, who is in charge of a ninety-bed unit for sports injuries and burns, quoted from Piragov, who said that "clever operations can only be done on clever patients" and stressed the importance of morale and psychic factors. Before leaving the Institute, we were taken to a very modern and beautifully equipped bank for preservation of bone and other tissues, including lyophilized skin.

The professors whom we visited in Leningrad and Moscow were all obviously top-notch surgeons of considerable prestige, and the young men and women working under them were receiving most thorough training. With regard to research—aside from the new instruments which have been developed—we were most impressed with the modesty and the realistic attitude of the laboratory scientists who were working at times in poor physical surroundings, but with real esprit de corps. These men are dedicated in the truest sense of the word. They are very well read and often quote from the literature of other countries.

The new instruments and stapling devices remain yet to be evaluated in this country. Some of them seem to be too bulky to be used effectively, it would appear, in areas where adequate exposure would be difficult to obtain. The possibilities of preservation of tissue and resuturing of human limbs are exciting and have given impetus to research in the field of transplantation. The basic work, however, of solving the homograft problem has not yet been accomplished, and it is difficult to see the practical value at present of some of the technical feats which we observed.

TRUMAN G. BLOCKER, M.D.
University of Texas,
School of Medicine,
Galveston, Texas

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A Rational Approach to Classification and Treatment of Fractures of the Surgical Neck of the Humerus

THEODORE DRAPANAS, M.D., JOHN MCDONALD, M.D. AND HARRY W. HALE, JR., M.D.,
Buffalo, New York

From the Department of Surgery, University of Buffalo School of Medicine, and the Edward J. Meyer Memorial Hospital, Buffalo, New York.

SINCE the introduction of the hanging cast, there has been considerable controversy concerning the treatment of fractures of the surgical neck of the humerus. Furthermore, this type of fracture has been variously classified in current textbooks, according to the presence or absence of impaction of the fragments, abduction or adduction of the proximal fragment of the head, position of the distal shaft fragment or combinations of these anatomic positions. Treatment based on these classifications has been variable and includes simple support with slings and bandages, hanging casts, abduction "airplane" shoulder spicas and open reduction.

Because of the multiplicity of plans of treatment based on these classifications, we have adopted a simplified approach which is dependent on the presence or absence of contact between the fractured bony surfaces, regardless of impaction, angulation or rotation of these fragments. We do not believe that this is a new or radical concept in the treatment of this group of fractures but one which is rather commonly appreciated by others although it is not clearly defined in the literature.

Our classification of these fractures into contact or non-contact types has greatly simplified our method of management; it is based on the belief that the fracture can be expected to heal rapidly and without incident if any contact of raw bone to raw bone is present. Therefore, in this instance, the preservation of shoulder function is most important. The earlier motion can be resumed after the fracture, the better will be the functional end result. On the other hand, if contact between fracture surfaces is not present, the situation is entirely different and much more difficult, and the results of treatment are much less satisfactory.

MATERIAL

A study of 100 consecutive patients with fractures of the surgical neck of the humerus who were treated at the Edward J. Meyer Memorial Hospital in Buffalo, New York, during the six-year period from 1951 through 1956 is herein discussed. Most of these were elderly patients admitted to the "house service," and a high percentage of them also had serious cardiovascular and pulmonary disease. This was the reason for hospitalizing 70 per cent of a group of patients with a type of fracture which usually would not require admission to a hospital. The remaining 30 per cent were treated on an ambulatory or out-patient basis. Seventy-five per cent of the patients were fifty years old or over. The youngest patient was three years of age, and the oldest was ninety-three. Eighty-six of these patients had a contact type of fracture while only fourteen

TABLE I
FRACTURES OF THE SURGICAL NECK

Type	No.
Contact	86
Non-contact	14
Total	100

TABLE II
CONTACT FRACTURES

Primary Treatment	No.
Sling and bandage	62
Hanging cast	20
No immobilization	3
Unknown	1
Total	86

patients had fractures which did not exhibit contact between the fracture fragments. (Table I.)

TREATMENT AND RESULTS

All patients were classified in the "contact" group if they had any contact at all between the raw sufaces of the fracture fragments regardless of whether or not abduction, adduction or impaction was present. The alignment of these fractures was not deemed important enough to warrant a separate or subsidiary classification. Table II shows the primary treatment which was used in these cases. Sixty-two patients, or 72 per cent of the contact group, were initially treated with a sling and bandage, or merely with a sling fastened to the clothing. In almost all cases this and the occasional use of small doses of codeine given orally produced relief of pain. The hanging cast was used in twenty cases, and it did not prove to be superior to simple sling support for this type of fracture. In two cases, distraction was noted within ten days after fracture. The hanging cast was re-

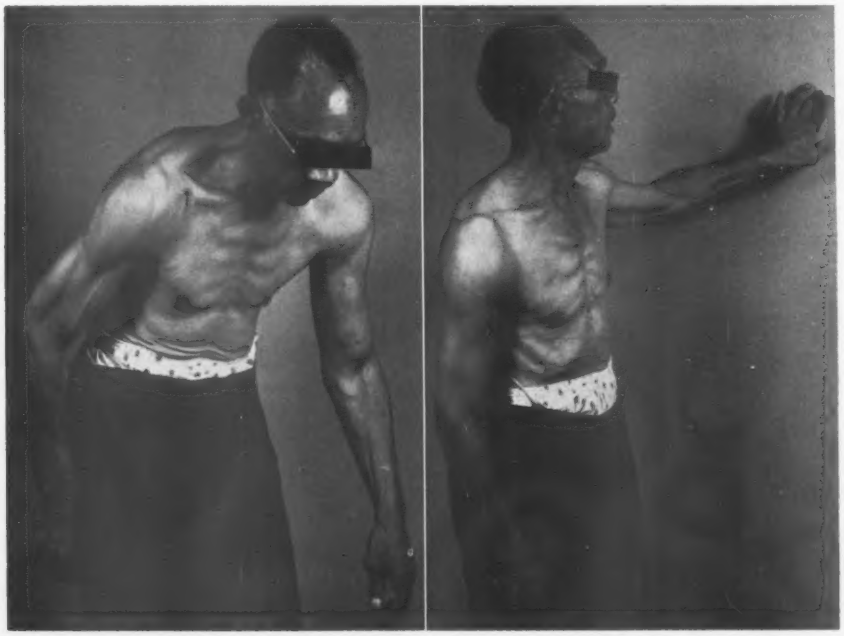

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FIG. 1. Patient M. N., aged sixty-five. Five days following contact fracture of the surgical neck of left humerus. Gravity-assisted pendulum exercises are being instituted within the limits of pain.

FIG. 2. Same patient. Two weeks following fracture. Abduction exercises are well tolerated and rather rapid improvement can be expected from this point.

placed with a sling, and healing followed. We agree with others that the weight of the arm itself causes sufficient traction to relieve pain, and that the addition of a cast may produce increase of pain and distraction of the previously contacted bony fragments. No form of external support was used on three occasions because of the presence of only minimal pain in the shoulder, and the initial treatment was not recorded in one patient, although subsequent follow-up showed good recovery of function.

It is particularly significant that manipulation to improve position was performed in only four instances, when some contact was originally present. In retrospect, we do not believe that was necessary in these four cases because roentgenograms demonstrated no improvement in position, and the fractures healed without complication in each case. Furthermore, it is entirely possible that a contact fracture might be converted to a non-contact one by manipulation, and this would be a highly undesirable result.

After the initial period of sling support, and when relief of pain permits, we have instituted daily active motion of the patient's shoulder joint. This usually begins within the first week with gradual, "gravity-assisted" circumduction exercises. The patient bends forward from the waist and describes a circle with the affected extremity in pendulum position. (Fig. 1.) Activity is increased within the limits allowed by pain; and as soon as they can be tolerated, active abduction exercises are initiated by having the patient stand next to a wall while he gradually abducts the arm from the trunk by "walking" up the wall with his fingers. (Fig. 2.) Internal rotation exercises are then begun by encouraging the patient to place the affected arm behind the back and try to touch the opposite scapula. The patient must be closely supervised and encouraged to perform these exercises. Usually two or three instructive sessions will suffice, but older persons may need repeated sessions or referral to a physiotherapist for concentrated activity. We have rarely found this to be necessary.

Table III shows the final results of treatment as judged from a functional standpoint in forty-two patients with contact fractures. All patients had primary bone healing. In the cases classified as "excellent" functional results the patients showed entirely normal movement of the shoulder with no limitation of motion.

TABLE III
CONTACT FRACTURES

Results of Treatment	No.
Excellent	17
Good	10
Fair	3
Poor	2
Usable shoulder but function not noted	10
Total	42

There were seventeen patients in this category. Ten patients were listed in the "good" category which was defined as a functional shoulder with mild restriction of motion to an abduction span of 90 degrees or more. The "fair" category included three patients who were still able to perform most of their routine tasks with motion limited to less than 90 degrees of abduction. Any restriction of function greater than the previously stated amounts produced a markedly disabled shoulder and was classified as "poor." There were two patients in this category. In ten cases, the data recorded were inadequate for purposes of classification, but the patient in each instance reported useful function in a telephone interview.

Figure 3 shows the roentgenogram of a contact fracture, commonly classified as the "impacted" variety. Treatment presented no problem, and emphasis was directed toward primary symptomatic relief and maintainance of function of the shoulder joint. Another example of a contact fracture is shown in Figure 4. Although marked comminution and "false" motion was present initially, this severe fracture was handled in the same way with the results as shown. Still another type of fracture, which we have classified in the contact group, is depicted in Figure 5. This type of fracture is commonly classified as abduction of the humeral head and neck. Because some limited bony contact was present, even though a considerable degree of rotation of the proximal fragment was noted, treatment was again directed at symptomatic relief and preservation of the motion of the shoulder.

It was extremely encouraging, to find that over 65 per cent of the patients with contact fractures had excellent motion of the shoulder with either complete or almost complete func-

FIG. 3. Patient T. G., aged forty-nine. Contact fracture showing impaction of the humeral shaft into the head with minimal displacement. Treatment with sling for seven days followed by active circumduction, abduction and internal rotation exercises. Complete and rapid recovery of function resulted.

FIG. 4. Patient J. D., aged thirty-three. A, contact fracture showing comminution of shaft with associated fracture of greater tuberosity. No impaction is present and false motion was clinically apparent. Treatment with sling and bandage for ten days resulted in marked relief of pain. Following this period, fracture was ignored, and physiotherapy directed toward early shoulder motion was instituted. B and C, follow-up studies at the end of six months show excellent anatomical union. Recovery occurred with no functional loss or weakness.

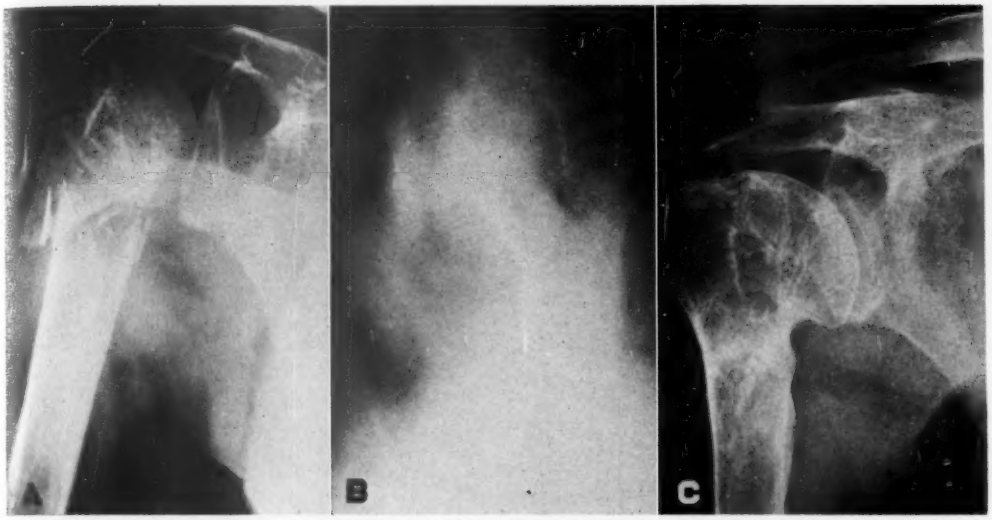

FIG. 5. Patient J. N., aged sixty-two. A, contact fracture, comminuted, with abduction and rotation of the head. Approximately 25 per cent of the fracture surfaces show contact. Treatment with light hanging cast for two weeks was followed by active motion. Functional recovery was slow, requiring active supervision in the physiotherapy department. B and C, follow-up roentgenograms three years later. At this time complete healing had occurred. Functional recovery was excellent.

tional return. An additional 30 per cent of the patients had either moderate restriction or claimed a useful shoulder and were satisfied with the results of treatment. We believe that the policy of early mobilization and concentration on exercise and maintainance of shoulder function is the most important single factor in therapy, particularly in the elderly segment of the population in which this fracture most commonly occurs.

The treatment of the non-contact fractures, however, presents an entirely different problem. These are all serious fractures, and the causative trauma is usually severe. The treatment is difficult, and the outcome is doubtful. Tearing of soft tissues, marked ecchymosis, and hematoma formatio nare almost always present. In addition, there is the real possibility of brachial plexus and vascular injuries from trauma caused by the jagged end of the shaft of the humerus which is usually adducted and pulled up into the axilla by the deltoid, pectoral and latissimus dorsi muscles. Fortunately these represent only a small portion of fractures of the surgical neck of the humerus. Our review includes fourteen such cases and, although the number is not large enough to warrant any definite conclusions and recommendations, they are presented to point out the problems involved.

Table IV shows the primary treatment instituted in this group. Open reduction was performed in six cases, utilizing various forms of fixation including metal splines in two cases, wiring in two cases, a staple in one, and reduction without fixation in the last case. In each instance, the method of fixation used was, in the opinion of the surgeon, the best means available of maintaining bone contact. Accurate reduction and firm fixation was frequently impossible because of comminution of the fragments.

Closed reduction by manipulation was successful in obtaining some contact in four

TABLE IV
NON-CONTACT FRACTURES

Primary Treatment	No.
Open reduction	6
Closed reduction	4
Non-reduced	4
Total	14

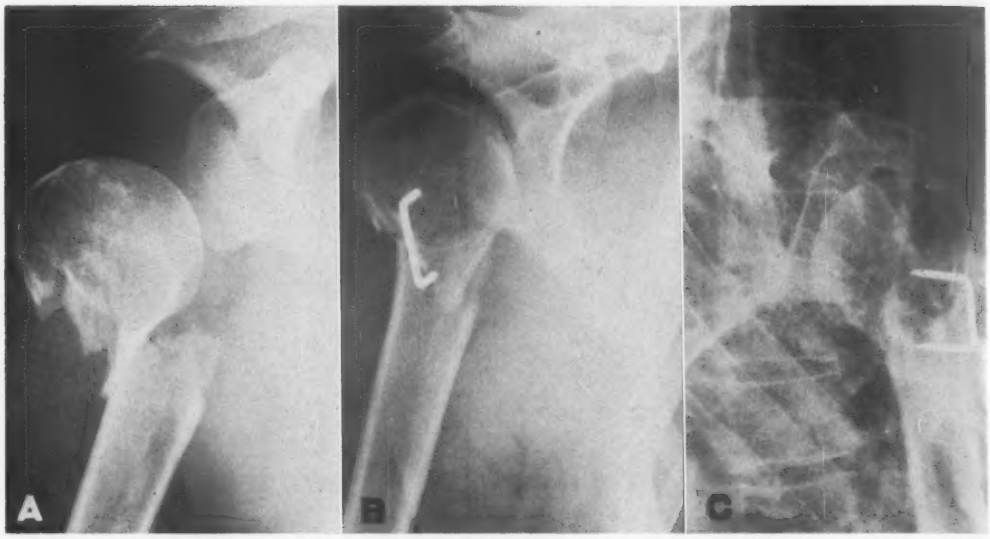

FIG. 6. Patient J. J., aged forty-eight. A, non-contact fracture with adduction of the shaft of the humerus. Bone contact could not be obtained with manipulation. B, open reduction with staple insertion was followed by sling and bandage support for two weeks. C, after one year there was excellent return of function.

patients, and this was accepted as primary treatment. Postoperative immobilization was maintained in three of these with a sling and bandage, and in the other, shoulder splints were used. Reduction was impossible in four patients. The latter group included two patients who were seriously ill from associated diseases which took priority in therapy. The two remaining patients are quite interesting and deserve detailed comment. One was an alcoholic who was admitted in delirium tremens. His fracture was discovered on admission to the hospital, but the date of the injury was never accurately determined. After a period of sobering, he had little pain with good motion and no definitive therapy was instituted. The patient was admitted again a year later with a fractured hip, and he learned to crutchwalk following Lorenzo screw hip fixation. He had no complaints referable to his shoulder joint, although the motion present was not accurately reported.

The other patient was seen four years after being treated for a non-contact fracture in which no reduction was accomplished for unknown reasons. At this time, false motion was present in the shoulder with no pain except following heavy exertion. This patient had a good range of motion at the site of fracture. He was entirely happy with the result and refused any further therapy. These two patients represent the development of a pseudoarthrosis at the fracture site which was functionally acceptable to them.

TABLE V
NON-CONCTACT FRACTURES

Results of Treatment	No.
Excellent	3
Open reduction (1)	
Closed reduction (2)	
Good	2
Open reduction (1)	
Closed reduction (1)	
Poor	3
Open reduction (3)	
Non-union but acceptable to patient	2
Total	10

The results of treatment in the non-contact fractures are summarized in Table v. An excellent result with a normal shoulder occurred in three patients on whom data was obtained: In one of these, open reduction was performed and maintained with a staple. (Fig. 6.) In the other two, contact was obtained by closed reduction and union resulted. A good result was obtained in two patients: one of them received an open reduction and internal fixa-

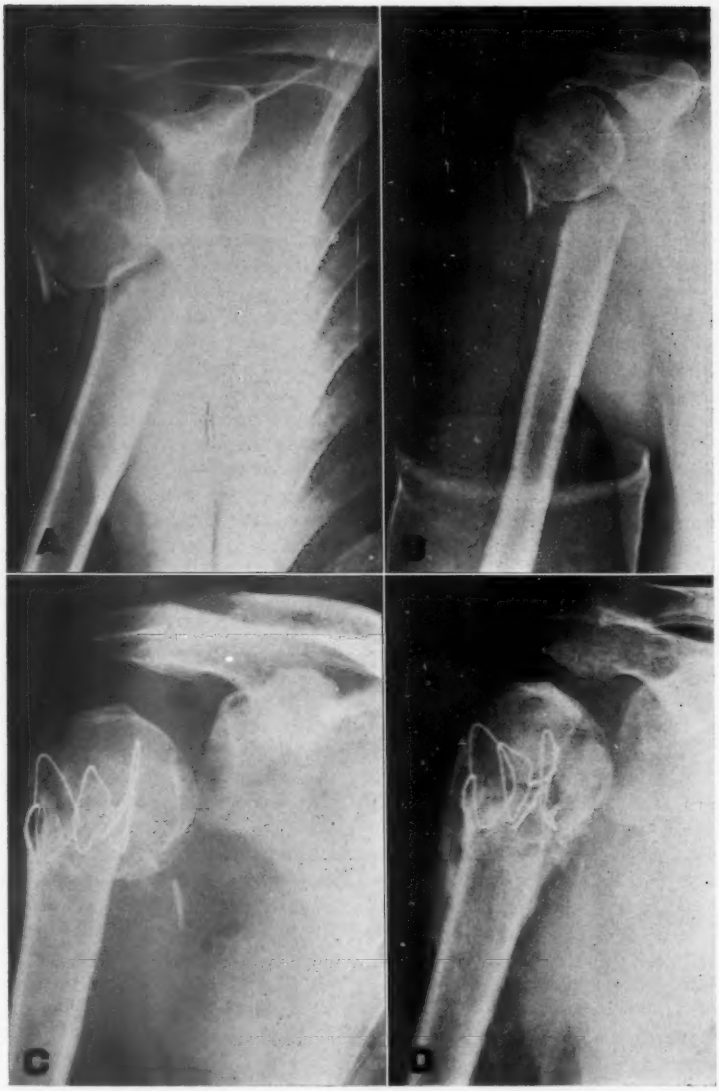

FIG. 7. Patient J. A., aged fifty-three. A, non-contact fracture with comminution of the head, marked rotation and abduction. Shaft adducted and shortened. B, application of hanging cast corrected the shortening but the head has spun completely around. No fracture contact present. C, roentgenograms following open reduction and wiring of fragments through drill holes and the use of sling support. Wound infection and osteomyelitis developed with a draining sinus. D, final result three years later. There is marked formation of callus. Functional result "poor" with abduction limited to 45 degrees and marked limitation of internal and external rotation.

tion, and the other a closed reduction. In all three cases in which the results were poor, the patients were treated with open reduction.

The difficulty in handling these cases is illustrated in Figure 7. In this patient, the shaft of the humerus was pulled into the axilla causing severe pain. A hanging cast was applied, and correction of the shortening resulted. However, the head remained completely rotated so that no contact was present. Open reduction and wire fixation were performed with difficulty because of the comminution present. Even though adequate reduction was obtained, postoperative infection and a draining sinus with osteomyelitis necessitated long immobilization. The functional result was poor with marked limitation of motion.

Although data were available on only ten patients who had non-contact fracture, it was apparent that if bony contact between fracture surfaces of the major fragments could be obtained by manipulation and maintained without internal fixation, this would be the preferred treatment. This was possible in four instances and an "excellent" or "good" result was obtained. Five patients who had had open reduction were available for follow-up study. Three of these had "poor" results, one was placed in the "excellent" category, and one had a "good" functional result. In two of the four patients who had non-contact and unreduced fractures pseudoarthroses developed which was functionally acceptable to them, and they refused further therapy. We believe that serious consideration should be given to avoiding open reduction in the elderly patient and in the patient for whom surgery is a risk. Furthermore, we believe that non-union should be accepted if closed reduction is not possible. In such patients, some function resulting from a pseudoarthrosis may be preferable to a strong but "frozen" or painful shoulder.

SUMMARY

A series of 100 cases of fracture of the surgical neck of the humerus is presented. These are divided into contact and non-contact types of fractures based on the presence or absence of contact between the broken fragments. This classification is simple, and it can be applied to all fractures of the surgical neck. The therapeutic and prognostic implications in the utilization of this classification, and illustrative cases, are discussed.

In the contact type of fracture, therapy is directed entirely at symptomatic relief by the simplest possible means. Sling support followed by early and concerted effort to maintain function of the shoulder joint should be used. No manipulation is necessary to improve position. Of the patients followed up in this group, all had primary union of the fracture and 65 per cent had complete or almost compete restoration of the function of the shoulder. An additional 30 per cent had moderate functional restriction but a useful shoulder.

Therapy is difficult in the non-contact type of fracture, and manipulative or operative treatment at the site of the fracture itself is usually necessary. Initial attempts should be made to obtain contact by manipulation, and if they are successful they should be accepted. When this does not suffice, open reduction and internal fixation should be used. Consideration should be given to accepting a non-union of the fracture in the elderly patient. In two such patients, a functioning and painless pseudoarthrosis was compatible with a moderately useful shoulder.

Radial Nerve Injuries in Fractures of the Shaft of the Humerus

ALEXANDER GARCIA, JR., M.D. AND BENJAMIN H. MAECK, M.D., *New York, New York*

From the Department of Orthopaedic Surgery, College of Physicians and Surgeons, Columbia University, and the Fracture Service, New York Orthopaedic Hospital, Columbia-Presbyterian Medical Center, New York, New York.

CONFUSION exists among surgeons on management of immediate nerve palsies complicating fractures of the shaft of the humerus. The treatment of such patients by operation and closed methods at the Fracture Service of the Columbia-Presbyterian Medical Center focused our interest on this problem and prompted the present study.

The records of over 500 patients with fractures of the shaft of the humerus treated since 1929 have been reviewed. Excluding fractures of the surgical neck and supracondylar and pathological fractures, there remained 226 fractures of the shaft in adults of which twenty-seven (11.7 per cent) were complicated by immediate nerve palsies. In addition there were four children with radial nerve palsies, making a total of thirty-one patients with immediate injuries in this series.

Twenty-four additional patients had radial nerve palsies after open reduction for fracture making a total of fifty-five patients with radial nerve injuries complicating fractures of the humeral shaft.

IMMEDIATE RADIAL NERVE PALSIES

Patients with immediate radial nerve palsies ranged from a newborn to a nonagenarian. There was a slightly higher incidence in women, but no predominance of either arm. As might be anticipated, in twenty-seven or two-thirds of the patients palsy was associated with fractures of the middle shaft. (Fig. 1.) The spiral oblique fracture with a butterfly fragment accounted for the majority of nerve injuries at all levels. (Table I.)

Twelve of twenty-one patients with complete paralysis had complete loss of sensation, while nine others had some radial nerve sensation. (Table II.) In ten patients with incomplete motor loss, the sensory deficit was incomplete, with one instance of no sensory loss.

Treatment. Of the thirty-one patients with immediate nerve palsies, twenty-three underwent surgery on or shortly after admission, eight were treated expectantly. Eighteen of the twenty-three who were operated upon made a complete recovery. Three had residual deficits and two were lost to follow-up.

Of the eight patients treated conservatively two were lost to follow up, three made a com-

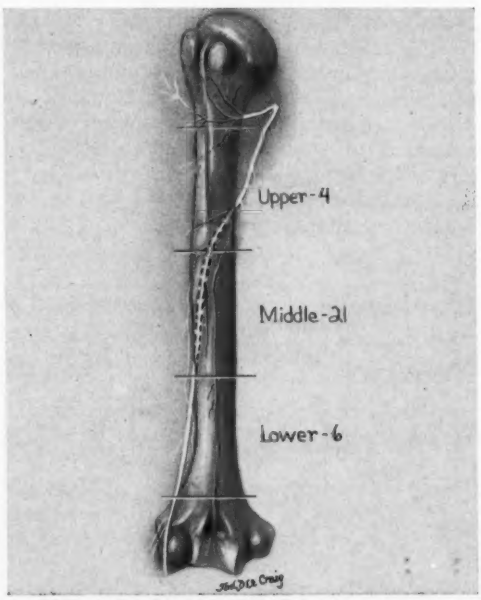

FIG. 1. Level of fracture in immediate radial nerve palsy.

TABLE I
IMMEDIATE RADIAL NERVE PALSY (THIRTY-ONE CASES)

Level	Total No.	Type of Fracture		
		Transverse	Spiral	Third Fragment
Upper third...	4	0	1	3
Middle third..	21	3	3	15
Lower third...	6	0	2	4

plete recovery and two had residual deficit. Surgery was advised but refused by one patient who still had not recovered after four years. The other patient was operated upon three and a half months later; the nerve was found to be severed and encased in callus. It was freed, resected and sutured. The suture line was enveloped with millipore. Not until nine months later was there partial return of nerve function.

In the majority of cases the nerve was merely examined or extricated from the site of the fracture, and the fracture stabilized usually by plating. When there was bruising of the nerve saline was injected beneath the nerve sheath. Primary suturing was carried out in one instance, with complete recovery.

A flap of muscle frequently was interposed to protect the nerve against the forming callus.

Operative Findings. The condition of the nerve was recorded at operation in twenty instances. It was interposed between the fracture fragments in seven patients, bruised in five, stretched in two, impaled in two, severed in one and normal in three.

TABLE III
RECOVERY AFTER IMMEDIATE SURGERY
(TWENTY-THREE PATIENTS)

Pathology	No.	Complete	Incomplete
Severed.....	1	1 (after suture)	..
Impaled.....	2	1	1
Bruised.....	5	5	..
Stretched.....	2	2	..
Interposed.....	7	7	..
Normal.....	3	2	1
Not recorded.....	3	2	1

TABLE II
INITIAL NEUROLOGICAL FINDINGS (THIRTY-ONE CASES)

Motor Loss	Total No.	Sensory Loss		
		Complete	Incomplete	None
Complete.....	21	12	6	3
Incomplete....	10	0	9	1

Recovery. In general the operative findings correlated with the recovery. In patients with bruised, stretched and interposed nerves recovery was complete; in those with one of two nerves impaled by fragments motor recovery was incomplete. In one patient with a nerve described as normal recovery was incomplete. (Table III.)

There is no constant relationship between operative findings and rate of return of sensation and motor power. In patients with nerves that were impaled, bruised, interposed or stretched return of function commenced within one week to four months after surgery. (Table IV.) In one patient with an apparently normal nerve there was no sign of recovery for six weeks and return was not complete for eight months.

It is clear that visible evidence of nerve

TABLE IV
RATE OF RETURN

Pathology	No.	Initial	Complete
Immediate Radial Nerve Palsy Treated Surgically (Twenty Patients)			
Severed.....	1*	8 mo.	4 yr.
Impaled.....	2	1 wk.–?	6 mo.–16 mo.
Bruised.....	5	1 wk.–3½ mo.	4 mo.–16 mo.
Stretched.....	2	1 wk.–?	10 mo.–?
Interposed.....	7	1 wk.–4 mo.	6 wk.–9 mo.
Normal.....	3	1 wk.–6 wk.	2 mo.–8 mo.
Immediate Radial Nerve Palsy Treated Conservatively (Eight Patients)			
Unknown.....	3†	1 wk.–3½ mo.	7 wk.–12 mo.

* Sutured.

† Two patients had no return; three patients were lost to follow up.

TABLE V

Pathology	No.	Residual
Complete Motor Loss (Twenty-One Patients)		
Severed	2	1
Impaled	2	1
Bruised	5	0
Interposed	7	0
Stretched	0	0
Normal	1	0
Not recorded or operated on	4	1
Incomplete Motor Loss (Ten Patients)		
Normal	2	0
Stretched	1	0
Interposed	1	0
Not operated on	3	0
Unknown	3	0

damage bears no constant relation to the rate of return of nerve function; it is equally clear that early initial return does not justify anticipation of early complete recovery.

The rate of recovery of patients undergoing surgery is comparable to that of patients treated conservatively; namely, there was initial return of nerve function within four months. (Table IV.)

The completeness of immediate radial nerve loss of function recorded at the time of injury has been correlated with the findings at operation and the residual deficit at follow-up. (Table V.) It is apparent that in patients with complete motor loss, the majority showed some visible sign of injury to the nerve at operation.

In patients with incomplete loss of motor function at initial examination, only two showed visible signs of injury at surgery.

TABLE VII
RESIDUALS OF POSTOPERATIVE PALSY
(TWENTY-FOUR PATIENTS)

Result	No.
Complete recovery	11
Residual motor deficit	3
Residual sensory deficit	6
Sensory and motor deficit	2
Inadequate follow up	2

TABLE VI
POSTOPERATIVE RADIAL NERVE PALSIES

Years*	Operations (No.)	Radial Nerve Palsy (No.)
1929–1939	56	17
1940–1949	24	7
1950–1959	22	0
Total	102	24

* In which operation was performed.

POSTOPERATIVE RADIAL NERVE PALSY

One hundred two patients with fractures of the shaft of the humerus with intact radial nerves were operated upon. In twenty-four of these postoperative radial nerve palsies developed. (Table VI.) One year after surgery eleven of these patients had some residual deficit. (Table VII.) However, during the past decade there have been no postoperative radial nerve injuries.

CONCLUSIONS

It is the policy of the Fracture Service at Columbia-Presbyterian Medical Center to operate upon patients with fractures of the shaft of the humerus when they present with definite evidence of radial nerve injury. Consequently this series has too few patients treated expectantly to permit statistical comparison of the two methods.

Since it is impossible to determine the condition of the radial nerve clinically, the conclusion may be drawn from this study that patients with complete nerve injuries should undergo surgery as soon after injury as possible, this being the only procedure which permits treatment when it is necessary. On the other hand incomplete palsy means that the fibers are intact and such patients should be treated expectantly. However, surgery should be performed at the first sign of progression of the paralysis. In addition patients who show no signs of improvement after four months should have the radial nerve explored. Obviously many patients who undergo surgery require no treatment. Many do, however, and with good surgical technic the rewards of early operation justify the risks.

Recurrent Anterior Dislocation of the Shoulder

I. MORBID ANATOMY

HARRISON L. MCLAUGHLIN, M.D., *New York, New York*

From the Department of Orthopedic Surgery, College of Physicians and Surgeons, Columbia University, and the Fracture Service of The New York Orthopaedic-Presbyterian Hospitals, New York, New York.

MULTIPLE patterns of morbid anatomy have been observed, described and indicted as the cause of recurring dislocations of the shoulder. That a theory on etiology was a prerequisite for each indictment has contributed to the confusion and controversy attending this condition. This discussion is not intended to denigrate the many observations already recorded, or even to argue with the seemingly conflicting theories which they have engendered; but rather, to suggest that few substantial grounds for argument really exist. Multiple patterns of morbid anatomy, alone or in combination, have been observed to produce a common etiological denominator which under appropriate circumstances permits recurrence of an anterior dislocation.

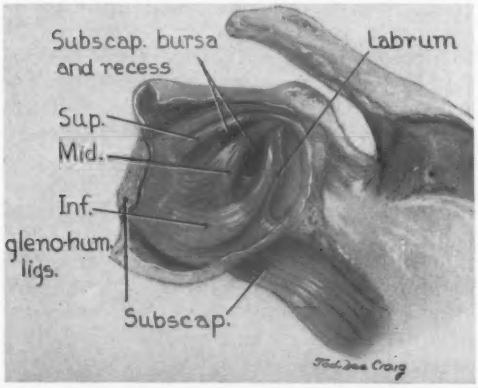

FIG. 1. The average disposition of the glenohumeral ligaments in the left shoulder joint, viewed from behind with the humerus removed.

The appropriate circumstances occur when the muscles defending the shoulder joint are caught off guard coincident with some motion which levers the humeral head from the glenoid over a fulcrum of the acromion, and the inelastic supports of the joint fail to do their job. It has become increasingly clear, as a result of operative findings, that some derangement or abolition of function of the glenohumeral ligaments is invariably responsible for the recurrence of dislocations of the shoulder. These observations are supported by several anatomical facts.

(1) The sole inelastic defense against forward displacement of the humerus from the glenoid is the triangular sling formed by the glenohumeral ligaments. (Fig. 1.)

(2) One or more components of this ligament sling normally serve to restrain the humerus against excessive abduction, extension and lateral rotation.

(3) Only an excess of one or some combination of these motions can activate the acromion as a fulcrum over which dislocation may occur.

(4) For adequate function the ligament sling, as a unit, must remain intact in continuity and must be stabilized so securely in position across the front of the joint that it slides neither over, under nor ahead of the forward moving humeral head.

That these ligaments are invisible except from within the joint, and even from this viewpoint often seem to be little more than thickened folds in the anterior joint capsule, does not detract from their importance. Virtually all the suggested causes of recurrent dislocation reflect some dysfunction of the tripartite sling which

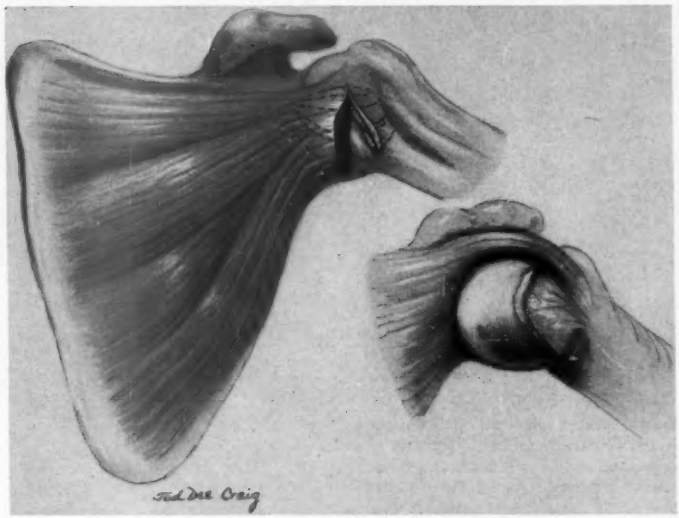

FIG. 2. Injury to the subscapularis insertion must also injure the glenohumeral ligaments (broken lines) conjoined with its deep surface. Subscapular instability is ligament instability (inset).

they form. Most of the recorded theories on the etiology of recurrent dislocation can be catalogued in five main categories which, with variations in detail and in variable combinations, have been described by a multitude of observers too numerous to cite.

The operative findings in a sample of fifty consecutive patients, personally observed, probably reflect an approximate index of the relative frequency with which these five entities constitute the crucial etiology of recurrent dislocations. (Table 1.)

It will be noted that there are fifty-five lesions and only fifty patients. This is because of multiple lesions which were common. In five instances double lesions, each of which was considered or proved to be crucial, were encountered. It was quite clear that multiple lesions, singly or in combination, could cause recurrent dislocations, and equally clear that all crucial lesions reflected or produced some dysfunction of the glenohumeral ligaments, each in its own peculiar way as outlined in the following.

Instability of the Subscapularis. Many primary dislocations are attended by some stripping up of the inferior joint capsule and subscapularis tendon from the humerus. Incomplete healing of a large rent of this type may leave the subscapularis hypermobile enough to slip over the top of the redislocating humeral head. (Fig. 2.) Transplantation of the subscapularis [1] is a widely utilized procedure for the prevention of future dislocations. But if, as is generally accepted, a prerequisite for recurrent dislocations is that the muscles spanning the shoulder joint are caught off guard, can the elastic subscapularis really be the true culprit? Subscapularis avulsion is glenohumeral ligament avulsion, for the two have a conjoined humeral insertion; imperfect healing of one is imperfect healing of the other,

TABLE 1
THE CRUCIAL* LESIONS IN FIFTY PATIENTS WITH RECURRENT DISLOCATIONS OF THE SHOULDER

Lesion	No.
Unstable subscapularis	4
Lax capsule with an anterior pouch	18
Gross avulsion of glenoid labrum†	25
Sleeve avulsion anterior capsule and scapular periosteum	8
Total	55

* Bone defects not considered crucial and not tabulated.

† There was glenoid labrum damage of some degree in the majority of all cases.

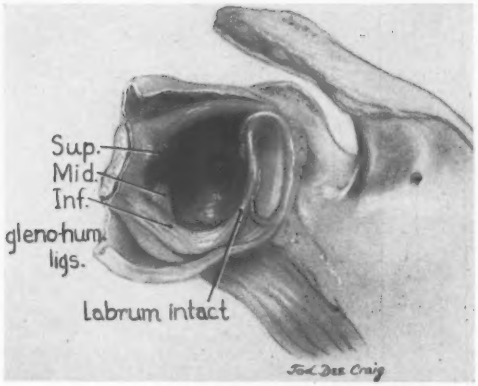

FIG. 3. Lax capsule with an anterior pouch. The left shoulder viewed from behind with the dislocated humeral head removed, illustrating the disposition of the soft parts for accommodation of the humerus in the anterior synovial pocket produced by rupture of the middle ligament.

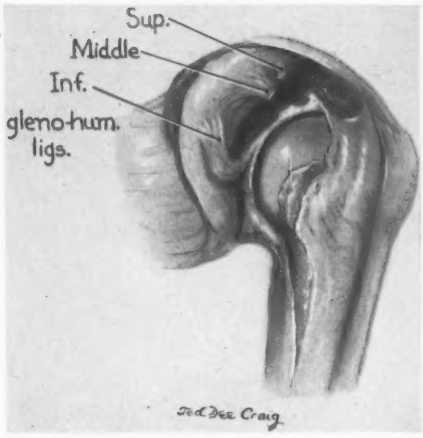

FIG. 4. Pseudo-sleeve avulsion. The subscapularis bursa and recess have been opened widely by rupture of the middle ligament, but the anterior labrum remains in place and the scapular neck retains its periosteal investment (See Figure 3 for disposition of tissues in the dislocated position.)

instability of one is instability of the other, and transplantation of the subscapularis cannot help but to restore tension, stability and an improved buttressing function to these ligaments. There seems to be little anatomical room for doubt that an inefficient and unstable subscapularis is synonymous with inefficiency and instability of the glenohumeral ligaments.

Lax Joint Capsule with an Anterior Pouch. The tiny superior glenohumeral ligament appears to have little significance as a restraining influence, except against hyperextension, and functions mainly as a guy rope from which the remainder of the ligament sling is suspended. (Fig. 1.) Destruction of this ligament alone has not been observed to permit dislocation, but often has been seen to contribute to instability of the other ligaments.

The middle glenohumeral ligament [2], in addition to its function as a restraining influence, serves as a partition without which the capacity of the anterior joint cavity would be increased by the cavities of the subscapularis bursa and recess. (Figs. 1 and 4). When this ligament is destroyed there is little left to prevent the humerus from slipping into this enlarged synovial pocket. Simultaneously the large inferior ligament, unsuspended and bereft of any substantial stabilization from above, slips under the advancing humeral head. (Fig. 3.)

When this pattern of morbid anatomy occurs, the glenoid labrum may be injured by the displacing humerus, but gross labrial damage is uncommon and avulsion does not occur, for the labrum is subject only to longitudinal traction by downward displacement of the inferior ligament. (Fig. 3.)

This pathological picture, therefore, is almost always characterized by a substantially intact anterior labrum, but the delitescent subscapularis recess may be opened widely by the displaced humerus. The findings then simulate a sleeve avulsion of capsule, ligaments and periosteum from the anterior surface of the scapular neck. This is an illusion (Fig. 4), for the glenoid labrum remains in place, and if the neck of the scapula is scratched with a sharp instrument it will be found to have a normal periosteal investment.

Avulsion of the Glenoid Labrum. This lesion, so well emphasized by Bankart [3], seems to be the most common cause of recurring dislocations of the shoulder. However, the anterior glenoid labrum is merely an appendage of the inferior glenohumeral ligament (Fig. 1), and can be avulsed only by this ligament. Once avulsed, the entire ligament sling, no longer stabilized from below, may slide ahead of and over the oncoming humeral head. (Fig. 5.) In long standing situations of this type the avulsed labrum shrivels, tends to disappear, and cannot be found at the time of operation.

Surgical interest and attention have re-

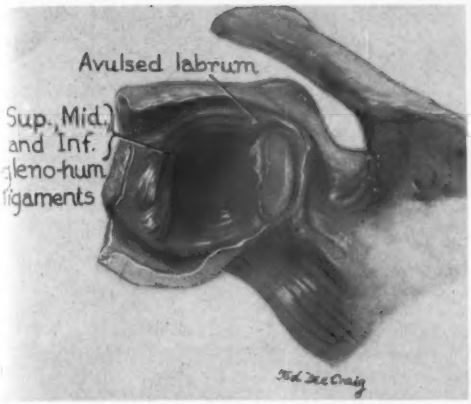

FIG. 5. Avulsion of glenoid labrum. The left shoulder viewed from behind with the dislocated humeral head removed. The entire ligament sling and labrum slide ahead of and over the advancing humerus.

FIG. 6. Sleeve avulsion. The anterior capsule, ligaments, labrum and scapular periosteum remain intact in continuity, but the periosteum has been peeled from the scapular neck so that the entire soft part unit may move ahead of the advancing humerus.

mained focused upon the detached labrum, but this lesion is, in fact, an avulsion from the scapula of the inferior glenohumeral ligament along with its functionally insignificant labrial appendage.

Sleeve Avulsion of Capsule and Periosteum from the Scapula. This pattern of damage is a variation of that reflected in avulsion of the glenoid labrum. The inferior ligament, instead of tearing free from the glenoid rim with the labrum, remains intact in continuity with scapular periosteum medial to the glenoid rim, but peels this periosteum from the anterior surface of the scapular neck. This entire soft part unit then no longer restrains, but may move forward ahead of the advancing humerus. (Fig. 6.)

Bone Defects. There can be little doubt that a hypoplastic glenoid facilitates traumatic dislocations, and may permit spontaneous dislocations. It has not been possible to implicate the length or disposition of the coracoid in the redislocation syndrome, although a fracture of this bone is sometimes produced by the dislocating humerus. A damaged and attenuated glenoid rim and a defect of the posterior humeral head [4] have been common findings. All the evidence has pointed to the fact that while the latter two defects undoubtedly facilitate anterior displacement of the humerus from the glenoid, both are the results and not the crucial causes of dislocations. It is anatomically apparent that neither can be produced until the glenohumeral ligaments first have been disrupted.

Pitfalls in the Interpretation of Operative Findings. All patients in the fifty cases tabulated in the foregoing have been followed up for at least ten years and the data are valid end results. There were three failures in which Bankart type repairs had been made for damaged and apparently loose glenoid labra. At the time of reoperation these repairs were found to be secure and intact despite continuing dislocations. Crucial concomitants of these labrial injuries had been neither recognized nor corrected at the time of the original operation. In one case the unrecognized lesion was an avulsion of the glenohumeral ligaments from the humerus; in the other two it was a disruption of the middle glenohumeral ligaments. Secondary repairs of these lesions were successful in preventing further dislocations.

These experiences warrant emphasis of the fact that the glenoid labrum is subject to damage as the humerus passes over the glenoid rim in every dislocation, whether or not recurring episodes ensue. It can also be damaged by non-dislocating injuries. Some labrial damage or detachment is the rule in almost all dislocating, and many non-dislocating, shoulders. Unless a true avulsion exists, labrial damage or looseness may not be the crucial lesion or the essential cause of recurring dislocations.

SUMMARY

Interest in the morbid anatomy of recurrent dislocation of the shoulder was prompted by the obvious incongruity between the integrity and accuracy of the multiple and variable

observations recorded, and the confusing and conflicting theories which they had engendered. As a result of our observations it is believed that there are no real grounds for argument, and that almost all recorded observations and valid theories on etiology can be reconciled with a single denominator which, in one way or another, represents damage to the ligament supports of the shoulder joint, even as is the case in dislocations of all other joints.

It has become increasingly clear that altered or absent function of the glenohumeral ligaments is this common etiological denominator, and that given an adequate operative exposure in a dry field, the pathomechanics of dislocation can be reproduced and the crucial lesion or lesions identified and repaired. One cannot refrain from concluding that this knowledge makes possible a more logical therapeutic approach than the current practice of utilizing some predetermined operation for all patients with dislocating shoulders without regard to or documentation of their morbid anatomical status.

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Football Injuries to the Shoulder Girdle

RICHARD PATTON, M.D., *Columbus, Ohio*

From the Ohio State University, Columbus, Ohio.

INJURIES to the shoulder girdle are common in football, ranking just behind injuries to the knee and ankle in frequency [1]. Two hundred and eighteen such injuries were seen in a series of 2,000 football injuries which occurred in the varsity football program between 1947 and 1957 [2]. One of every three football injuries to all areas causes disability. Injuries to the shoulder are more serious. Over half caused some disability as measured by time lost from practice or game.

The proper approach to the management of athletic injuries requires the following program: (1) diagnosis, (2) supervised conservative treatment, including active exercise until function is normal or operative repair, and (3) decision as to when and if athletic activity can safely be resumed.

Anatomically the stability of the entire shoulder girdle is dependent on muscular support. In all injuries to the shoulder it is essential that muscular strength be returned to normal before active participation in sports can be resumed.

Minor Injuries. Bruises, contusions and muscle strains in the region of the shoulder occurred one hundred and eight times. The deltoid and trapezius muscles were the most commonly involved and with almost equal frequency. These lesions are treated conservatively by the immediate application of ice and pressure which is continued for twenty to thirty minutes. The "hot pack" or antiphlogistic ointment is then applied under a heavy cotton bandage and held in place with mild pressure. Active motion is urged. Physiotherapy consisting mainly of infrared or moist heat and massage is started in twenty-four hours and continued until local tenderness and soreness have disappeared. Additional protection is used as necessary in the first few days following the injury. If a hematoma is palpable in the muscle it is usually injected with 10 to 15 cc. of ½ per cent procaine solution containing 500 units of hyalouronidase. As a rule this palpable mass is small and tender. It is responsible for prolonged soreness unless it can be dispersed. The blood is extravasated through the area of the injury. It is seldom liquid, and attempts at aspiration are unsuccessful.

Acromioclavicular Separation. Sixty-eight acromioclavicular injuries, all disabling, were recorded. This common football injury occurs in one of three types of degrees. These types are: (1) a sprain or strain with partial tearing of the acromioclavicular joint capsule and ligaments, (2) rupture of the acromioclavicular joint capsule and ligaments, and sprain of the coracoclavicular ligaments, and (3) dislocation of the acromioclavicular joint because of complete rupture of the acromioclavicular and coracoclavicular ligaments.

The first degree of acromioclavicular injury is the most common. Three out of four injuries were of this type. Moderate pain over the tip of the shoulder occurs immediately, followed in a few hours by stiffness of the shoulder joint, difficulty in raising the arm, and soft tissue swelling over the acromioclavicular joint. Within a few days the soft tissue swelling and pain on motion of the shoulder joint improve, but tenderness directly over the acromioclavicular joint is still present. Little abnormal motion between the outer end of the clavicle and acromion occurs at any time in this degree of acromioclavicular separation. In the reported series the average time of disability was one week.

The second degree of acromioclavicular injury was less common than the first. It was seen in 25 per cent of the patients. The immediate injury is moderately painful. Inability to raise the arm occurs immediately following the injury, and pain on motion in the shoulder

girdle is severe. On examination an abnormal elevation of the clavicle is apparent, and some abnormal motion between the clavicle and acromion can be demonstrated on examination and by x-ray film. The elevation of the clavicle usually amounts to not more than a quarter of an inch but it can be demonstrated both by physical examination and roentgenograms of both shoulders taken while three to five pounds of weight are being held in each hand. The shoulder remains tender and sore for two to three weeks and physical contact should not be allowed until the tenderness has disappeared. The average time lost from football in this type of injury was two weeks.

The third degree of acromioclavicular separation was seen only twice in the present series. In this degree the clavicle rides high entirely out of the acromioclavicular joint, and diagnosis can be made with ease on physical examination and confirmed by x-ray film. In order to prevent recurring dislocation of the clavicle aggressive conservative treatment or operative repair is necessary. Conservatively the lesion may be reduced and then held in place by pressure, cast and bandage for a period of six weeks, or surgically the clavicle may be held in place by fixation to the coracoid with a heavy suture or screw, and the ligaments repaired.

A full discussion of the surgical treatment of the third degree, complete dislocation of the acromioclavicular joint, is not within the scope of the report being presented. In two cases in the present series and in other acute dislocations, a satisfactory repair was accomplished by firm fixation of the clavicle to the coracoid with a heavy wire suture or screw, and suturing of the torn acromioclavicular ligaments about the joint. In general the repair of the old or chronic dislocation will require resection of the distal ½ inch of the clavicle and fixation of the clavicle to the coracoid process [*5,6*].

The treatment of the first two degrees of injury to the acromioclavicular joint is conservative. It consists of the following: (1) resting the shoulder by means of a sling support, (2) cold compresses on the outer end of the clavicle immediately following injury to reduce swelling, (3) physiotherapy and early active motion, and (4) injection of the acromioclavicular joint with corticosteroids.

A great number of appliances have been advocated in the conservative treatment [*3*]. As far as can be seen in the present series these provide only rest and hence relieve pain. After testing various types of bandages, suspensions and harnesses the conclusion has been reached that they provide pain relief due to rest of the shoulder. Slight to moderate elevations of the clavicle following the injury are not permanently reduced by the bandages, slings and harnesses and complete reduction is unnecessary in that a normal functional result occurs without it. A combination body cast and elastic strapping support have been described which have been satisfactory in holding the clavicle in position [*4*]. If a perfect cosmetic as well as normal functional result is desired, this method has merit.

Persistent pain and tenderness in the acromioclavicular joint after the acute reaction to trauma has subsided have responded to local injection of corticosteroids. This period of acute reaction lasts three or four days in the first type and eight to ten days in the second. The earlier use of corticosteroids locally has been followed by an increase in pain and swelling rather than improvement.

Obviously it has been possible to follow these acromioclavicular injuries through the period of repair and continued participation in football. The occurrence of a similar lesion in the opposite shoulder following injury is not uncommon but recurrence of the same injury is uncommon. The impression gained from this series of injuries is that conservative treatment of the first two degrees of acromioclavicular separation results in normal motion for normal activity and a strong shoulder for the vigorous contact seen in football.

Brachial Plexus Injury. A lesion diagnosed as traumatic irritation through stretching of the brachial plexus has been seen in fourteen football players in the past ten years. This syndrome is characterized by a shocking, numbing pain in the arm following a blow to the head, neck and shoulder such as occurs on blocking and tackling. Accurate diagnosis is difficult because except during the short period of time directly following the injury these patients have minimal symptoms, complaints and findings. Symptoms are brought on by a blow that forces the shoulder downward or the head and neck to the opposite side. The pain is shocking and severe and is accompanied by a numbing sensation in the arm and inability to move it for a few moments. Examination directly following the injury shows a diminished sensation to pin prick but no anesthesia. This has developed into a recurrent problem in almost half our pa-

tients and frequent episodes following this type of a blow have been seen. However, even in players with recurrent attacks of this syndrome who have been followed up three or four years since injury, no residual neurologic defects have ever been demonstrated. Pain can be reproduced on examination by sharply moving the head toward the opposite shoulder.

The mechanism of injury is believed to be a strain or rupture of muscles in the posterior triangle of the neck, trapezius, levator scapula and medial scalene with resultant scarring which interferes with normal lateral bending of the neck and produces tension on the brachial plexus.

The treatment of the acute attacks is rest and physiotherapy. Awareness of the chronic problem has indicated prolonged conservative treatment before return to football. When local tenderness and soreness have disappeared, active exercise of the neck muscles is practiced until they have attained their normal strength. Careful conservative treatment of the acute injury will allow complete recovery without recurrence.

Many of these problems when first seen are chronic, the acute injury having occurred previously in football. The attacks at this time may be of almost daily occurrence. Two facts have been noted which have been of help in handling the situation. First, these players have weakness of the muscles involved which can be demonstrated on examination. Second, they tend to duck their heads so that the neck is in a position of flexion on blocking and tackling. Treatment then has been directed at active exercise against resistance to strengthen the neck muscles, and training of the player to fix his head in extension during blocking and tackling.

Lesions of the Rotator Cuff. The lesions of the rotator cuff seen in football players of college age are entirely different from those seen in older persons. Partial tears of the supraspinatus tendon or rotator cuff have been diagnosed eleven times. The diagnosis has been made because of shoulder pain following injury associated with tenderness beneath the acromion and inability to normally abduct the arm. No calcific deposits have been noted. These lesions tend to be acute and self-limited. They have responded rapidly to initial cold applications followed in forty-eight hours by heat applications, massage and early active motion. A few of these patients have required novocaine and corticosteroid injection before complete relief is obtained. Chronic pain in the shoulder has not been noted.

Sternoclavicular Separation. This has been an uncommon lesion, seen only three times in the present series. A sternoclavicular separation is characterized by pain and swelling at the sternoclavicular joint and abnormal mobility of end of the clavicle. Healing occurs in two to three weeks and is aided by physiotherapy. No splinting is necessary but a sling during the acute process is helpful to relieve pain. After recovery, recurrences have not been seen. When swelling and tenderness disappear and normal motion in the shoulder girdle is possible, the player may return to football.

Shoulder Dislocation. Primary dislocation to the shoulder has been seen on only two occasions in the past ten years. Both of these dislocations were reduced by traction. Conservative treatment consisted of immobilization for three to four weeks, followed by three weeks of active exercise before the player returned to football. A harness was then used to prevent abduction during the rest of the football season. Neither of these players has had recurrence.

We have had three players who entered Ohio State University with recurrent shoulder dislocation as a chronic problem. Despite a harness to prevent abduction, recurrent dislocation was seen a number of times in these persons. Reduction of the recurrent dislocation by simple weight traction was uniformly effective.

SUMMARY

1. Injuries to the shoulder girdle are common in football.

2. These injuries are discussed in the order of frequency, from the standpoint of the physician managing the treatment.

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The Treatment of Ruptures of the Distal Biceps Brachii Tendon

J. Minton Meherin, M.D. and Eugene S. Kilgore, Jr., M.D., *San Francisco, California*

Rupture of the distal tendon of the biceps brachii is an uncommon lesion. No one has seen very many. However, a canvas of one's colleagues reveals several who have had one to three such cases, and isolated and small groups of cases are not infrequently reported in the literature [4].

The varied opinions concerning the importance of the functions of the biceps muscle have led to different concepts of treatment of the ruptured distal tendon. Some believe it should be reanchored distally, and some believe operative repair is not necessary.

Kinesiologists agree that the biceps muscle through its distal tendon is a supinator and a flexor of the forearm. Its maximum supinator force is exerted when the elbow is in flexion, and its maximum flexion force is exerted when the forearm is in supination. Results of laboratory investigations differ on the degrees and efficiencies of these two functions [2,9,12]. This explains in part the different concepts of treatment of the ruptured tendon.

The role of the biceps in supination and flexion must be considered very important by those who advocate reanchoring it distally and of little importance by those who advocate nonoperative treatment. It was hoped that this difference might be resolved if a number of patients were evaluated after reaching their maximum recovery. Twenty-two such cases were reviewed. Thirteen patients who had been operated upon and nine who had been treated conservatively were followed up for nine to twenty months.

The tendon was completely avulsed from the tubercle in all those patients operated upon except one, in whom a few fibers remained attached to the periosteum. In only one patient was part of the tubercle itself avulsed, and this was detected by x-ray examination. In all patients who were operated upon late, there was considerable scarring in the antecubital fossa. At times the scarring also involved the musculotendinous junction and gave the initial impression that the rupture might have occurred at this site. In other instances the scarring distal to the muscle simulated the intact tendon. In one such patient, whom we operated upon four months after injury, the paratenon had the appearance of a scarred tendon running to the radial tubercle. When this structure was further dissected, it proved to have a lumen in which the retracted tendon had lain for some time following the injury. Gross and microscopic examination of the cadaver failed to reveal a tendon sheath around the distal biceps tendon to account for this tubular structure. Tearing of the lacertus fibrosus was not found in any of these patients.

The Henry approach or minor modifications thereof was used in all cases. Of the total twenty-two patients, twenty-one were awarded some permanent disability. This was three times higher in those treated conservatively than in those operated upon (21.3 per cent vs. 7.2 per cent). To explain these percentages it should be understood that much credence is given to the patients' complaints of pain, tenderness and loss of strength. The broadest interpretation is placed upon the surgeons' reports of loss of function. Indeed, clinically these patients are better than the percentages of disability indicate.

All patients were males ranging in age from thirty-eight to sixty-five years, with an average age of forty-nine. There were thirteen operated upon with the average age of forty-nine, and nine treated conservatively with the average age of fifty. Certain facts were ascertained from this material. (Tables I and II.)

All injuries resulted from forceful flexion of

TABLE I

Treatment	No. of Cases	Disability* (%)	Range (%)
Operative			
Reattached to radial tubercle	6	7.2	3.25–10
Attached to brachialis tendon	4	7.1	0–16.75
	10	Average, 7.2	
Conservative	9	21.3	12.25–33.5

* Permanent disability rating rendered by the State of California Industrial Accident Commission.

TABLE II

Miscellaneous Operated Cases	No. of Cases	Disability (%)
Missed diagnosis, pathologic condition not recognized	1	21
Biceps tendon attached to ulna, infected	1	31.25
Operative procedure not known, permanent radial nerve paresis	1	13.75

the forearm in supination against sudden resistance. The symptoms common to most were: (1) a sudden painful snap in the antecubital fossa; (2) diffuse pain with all motions of the forearm with consequent restriction of motion; and (3) tenderness in the antecubital fossa and pain with flexion and supination of the forearm persisting for long periods.

The signs common to most were: (1) immediate swelling and tenderness in the antecubital fossa; (2) extensive ecchymosis of the distal arm and proximal forearm; (3) limitation of all movements of the forearm; (4) high riding, abnormally prominent, contracted biceps muscle belly; and (5) uncertainty about the absence or retraction of the biceps tendon from the antecubital fossa.

The correct diagnosis was made in all except one case, although in several it was not made immediately. X-ray examination was helpful in establishing the diagnosis in only one case in which part of the tubercle was avulsed.

The conclusion reached from this study is that conservative treatment is unsatisfactory. It has not relieved the persistent pain and tenderness which is continually aggravated by movements of the forearm and the lifting of light objects.

Fixation of the tendon distally does relieve the pain and tenderness. Theoretically and ideally this ruptured tendon should be reattached to its insertion on the radial tubercle, but the advisability of this procedure is open to question. It should not be avoided because it is tedious and hazardous if the results justify its performance. However, there have been several cases of permanent partial radial nerve damage in other series and three in ours. Various methods have been described to reattach the retracted tendon to the tubercle. These procedures may, when completed, appear to have accomplished an ideal repair, but whether or not the complicated function of the biceps muscle has been permanently restored may be equivocal. In two cases in this series in which the tendon was firmly reattached to the tubercle by a wire suture through drill holes, the suture had broken in the postoperative period and there was evidence that the tendon had retracted. If all sutures used in the tendon repair had been radiopaque, one might have found others.

The alternative procedure of attaching the ruptured tendon to the tendon of the brachialis muscle is less hazardous, less tedious and equally effective. This has been established by this group of cases as well as those reported by Dobbie [4].

One might believe that the loss of flexion and supinator force in those cases in which the ruptured tendon was attached to the tendon of the brachialis muscle would be definite. This was not demonstrated in our cases. It is possible that some biceps flexion force is restored by its attachment to the brachialis tendon. Some supinator force is surely lost. Actually, when excessive supinator force is needed, the elbow is involuntarily moved away from the rib margin and the arm is adducted and externally rotated, thus bringing the muscles of the shoulder into this action. Rough tests on normal subjects measured on a spring scale show that this maneuver adds approximately 10 to 20 per cent force to the power of supination.

SUMMARY

Twenty-two patients with rupture of the distal tendon of the biceps brachii, who had

been followed up nine to twenty months to their maximum recovery, are reviewed.

Twenty-one cases were adjudged to have had some permanent disability.

Thirteen patients were operated upon and nine treated conservatively. The average permanent disability rating established by the California Industrial Accident Commission for those treated conservatively was 21.3 per cent (nine cases). For those operated upon by reattachment to the radial tubercle, the rating was 7.2 per cent (six cases). For those operated upon by attachment to the tendon of the brachialis muscle, it was 7.1 per cent (four cases).

The unrelenting pain following this injury is best relieved by surgery.

CONCLUSION

The treatment of choice for rupture of the distal tendon of the biceps brachii is its attachment to the tendon of the brachialis muscle.

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DISCUSSION OF PAPERS BY DRS. DRAPANAS, MCDONALD AND HALE; GARCIA AND MAECK; MCLAUGHLIN; PATTON; AND MEHERIN AND KILGORE

Preston A. Wade (New York, N. Y.): The first paper, by Drs. Drapanas, McDonald and Hale, is a timely one and interests me greatly, particularly because of the reference to the hanging cast. The résumé in the program begins, "Since the introduction of the hanging cast in 1933, a considerable controversy has existed." As a matter of fact, the hanging cast for the surgical neck of the humerus is a dreadful treatment. It seems this type of cast fascinates anyone who hears there is a fracture involving the upper extremities, regardless of where it is or how it happened. I was pleased that Dr. McDonald apologized for the number of cases in which the hanging cast was used, twenty of sixty-eight. However, I do not think he has to apologize; he should be proud that all sixty-eight were not treated in this manner. I have found that these patients with broken arms have to be guarded so as to prevent the use of a hanging cast in every case. Theoretically, a hanging cast is designed to distract the fragments, and that is the last thing you want to do to the surgical neck of the humerus. Dr. McDonald said the most important objective was rehabilitation and preservation of motion of the shoulder joint. Therefore, if a weight is hung on the arm immobilizing the tired shoulder muscles, the healing is being delayed. The only thing we can be happy about is that nature, despite the hanging cast, usually permits a good result. My friends have argued with me about the hanging cast, saying, "Well, maybe you do not like the hanging cast, but we have used it for twenty years with good results." My answer is that if the hanging cast were to be used on the opposite sound arm, better results would be obtained in the injured one because the injured limb would get the treatment it needs, that is, active motion.

My conclusion is that it is time to bury the hanging cast. We like to treat unstable fractures connected with the upper end of the humerus (a high shaft, but an unstable one) with intramedullary nails. I think the intramedullary nail is much more effective than other wires and methods.

Drs. Garcia and Maeck's paper on fracture of the humerus with radial nerve injury is a very fine one. I must say I am still a bit confused about whether or not I should advocate early exploration of the radial nerve of the humerus. At our hospital we do not always perform immediate exploration. I think, and Dr. Garcia will correct me if I am wrong, that if there is a complete paralysis, he would do an immediate repair, and in so doing would expect to get a better result than if he waits longer.

Regarding the paper by Drs. Meherin and Kilgore, in our experience the repair is best accomplished by transplanting the distal end of the biceps to the brachialis; we have uniformly good results.

FREDERICK M. SMITH (Falmouth, Mass.): I would like to make a few comments on the paper by Drs. Garcia and Maeck. They split the cases of postoperative paralysis into three decades—1929 to 1939, 1940 to 1949 and 1950 to 1959. In the first decade there were fifty-six patients operated upon with seventeen resulting in postoperative paralysis. In the next decade twenty-four were operated upon with seven instances, and in the last decade twenty-two operations with no paralysis. I think the reason for this is that in the first decade we were operating upon a great many more patients than we should have been. Undoubtedly there was some overenthusiasm. In the last two decades, if Dr. Wade will excuse me, we have resorted to the use of a hanging cast in some comminuted fractures of the humeral shaft, and I think a great many patients have been spared the operation and the paralysis. I know also that the operative technic has been better in the last two decades.

I would like to ask Dr. Garcia what treatment was given the radial nerve after the operation; was the paralysis a primary nerve paralysis or one resulting from the operation? Did he use a cock-up splint, physiotherapy, nerve stimulation, or what?

Drs. Meherin and Kilgore described rupture of the distal biceps, certainly an unusual type of injury. It is said in the literature (and information is sparse) that it usually comes from lifting heavy objects. I have seen three such cases, and two were not from lifting but from sudden jerks. One patient was holding a rope attached to a bucket which he threw overboard while on a moving boat; the bucket caught in the water, jerked his arm and he ruptured the distal biceps. The most recent patient was holding on to the railing of a companionway of a boat. The boat lurched, and to save himself he held on; his whole body went forward, and he tore the biceps tendon from the tuberosity.

Replacing the tendon to its original attachment is an interesting procedure but quite technical. It certainly has inherent dangers, and I believe the attachment to the brachialis tendon is probably satisfactory and gives just as good a result.

SIR REGINALD WATSON-JONES (London, Eng.): I would like to add my endeavor to that of Dr. Preston Wade's about burying the hanging cast. It is the worst sort of treatment I know for any fracture of the shaft or neck of the humerus. I was brought up to treat these fractures with the collar and sleeve sling. This is not as bad as a hanging cast but it is still bad, because even the weight of the limb itself is enough to distract not only the fracture but also the shoulder joint. This downward subluxation of the shoulder joint is seen even when there is a fracture of the neck of the humerus, as the result of the weight of the limb. It is true it will usually recover as the muscle is regained. Why aggravate that danger? Why not support the limb instead of hanging it?

In the paper of Drs. Garcia and Maeck I noted the high number of radial nerve lesions occurring after operation on a fractured humerus in which there had been no primary lesion. I see that frequency just as much in England as you apparently do in America, and I have a firm, absolute, resolute determination in any fracture of the middle of the shaft of the humerus upon which I propose to operate and which I teach all my students: the first part of the operation is exposure of the radial nerve, and no one must begin the operation on the bone until he has exposed the radial nerve from just above the elbow to above the level of the fracture. Failure to do that involves running a very grave risk no matter how skilled the surgeon is, because in these fractures the position of the radial nerve is anyone's guess. The most skilled and expert anatomist in the world can go wrong. Therefore, I always start the operation and say to those around me, "I am first going to expose the radial nerve, and I shall do it before I start on the bone." The bone operation only takes ten or fifteen minutes, but I will always start on the radial nerve and expose it even if it takes an hour.

A. P. AITKEN (Brookline, Mass.): I wish to make one comment on fractures of the surgical neck of the humerus. When reviewing x-ray films, we must be quite sure that all we have is a fracture of the surgical neck of the humerus. At the City Hospital in Boston we see a large number of these, and we have become quite chagrined in the past two or three years to find some patients who did not do well after suffering this type of fracture. Despite the fact that in all cases a lateral view is taken through the chest, we have missed two very serious injuries: one, a posterior dislocation of the head of the humerus and the other, a posterior dislocation of a large fragment of the head. These fractures and dis-

locations are very easy to miss. I have the dubious distinction of having missed two within the past two years. These injuries are very serious because most of them are discovered late. However, even if they were discovered early, treatment would be extremely difficult. In the patient with a posterior dislocation of the head, complicating what appeared to be a simple fracture of the neck, we also found a depressed fracture of the glenoid, which made reduction very difficult.

I think everyone treating surgical neck fractures should be certain they have adequate x-ray films and thereby make quite sure there are not some other much more serious injuries present, such as dislocation or displacement of a large fragment of the head.

ALEXANDER GARCIA (closing): Our feeling about whether or not to operate on immediate complete motor palsies of the radial nerve is predicated on the fact that clinically we cannot tell how much damage has been done to the nerve at the time of injury, and we think that in the hands of the careful surgeon early exploration gives the best opportunity to look at the nerve and stabilize the fracture, and perhaps do a great deal of good without harm.

Regarding the postoperative management, in the early cases in the 1920's and 1930's a cock-up splint and lots of nerve stimulation were used; in the later 1930's and 1940's, a cock-up splint and practically no nerve stimulation were employed. I think what Sir Reginald said certainly is very important, and I think our statistics rather bear it out. During the last ten years there were no radial nerve injuries following reduction and internal fixation of fractures of the shaft of the radius.

Millipore is a substance which permits the passage of tissue fluids to the suture line without allowing fibroblasts to grow into the area. It has this advantage at least in experimental animals; we have had very little clinical experience. However, it has some theoretic basis, and I think it may permit nutrition to the neurons without interference from fibroblasts.

E. S. KILGORE, JR. (closing): In answer to Dr. Wade, we advocate that the procedure of reattaching the biceps tendon to the radial tubercle be abandoned. It has caused permanent injury to the radial nerve. The simpler procedure of attaching the biceps tendon to the brachialis tendon does not involve this risk, and gives an excellent functional result.

Management of Perforating Injuries to the Colon in Civilian Practice

W. R. Roof, M.D., George C. Morris, Jr., M.D. and Michael E. De Bakey, M.D., *Houston, Texas*

From the Cora and Webb Mading Department of Surgery, Baylor University College of Medicine, Houston, Texas.

Mortality and morbidity from acute injuries to the colon have been reduced continuously by aggressive surgery during the twentieth century. Although improved anesthesia, fluid and blood replacement and the use of antibiotic and chemotherapeutic agents have contributed greatly to the reduction in mortality, definitive operative repair of the injury has been largely responsible for the improved results. The technical procedure of choice, however, has remained controversial. During World War II the routine practice of exteriorization of the damaged colon as the first phase of a two-stage repair was credited with markedly increased survival rates [*5,6,8*]. This form of therapy was carried into civilian practice in the postwar years and still has many advocates. Other surgeons have urged that selected patients be treated with primary repair [*10,14*].

The present report is an analysis of 186 cases of traumatic lesions of the colon seen during the past ten years at the Jefferson Davis Hospital. The majority of these patients were treated by primary repair. Included in the series are the results previously reported from this institution in 1956 by Pontius, Creech and De Bakey [*10*].

MATERIAL

From January 1949 to January 1959, 186 patients were operated upon for traumatic lesions of the colon. Over 90 per cent of these patients were young adults between fifteen and forty-five years of age. Two-thirds of the patients were Negro and the remainder almost equally divided between Latin Americans and all other white races combined. Males outnumbered females by a ratio of four to one. Mode of injury in order of frequency was bullet, knife, shotgun and blunt trauma. (Table I.) Multiple injuries to the colon were encountered in 20 per cent of patients, and the majority were the result of firearms. The transverse colon was injured most frequently, followed in order of diminishing frequency by the descending colon, ascending colon and rectosigmoid. Wounds by firearms were almost equally distributed about the colon but the majority of knife wounds involved the transverse colon. Bullets ranged in size from .22 through .45 calibres and were usually low velocity missiles. The high velocity injuries were usually in patients wounded by peace officers. Shotgun wounds were caused by pellets ranging from No. 12 through 00 discharged from shotguns ranging in size from .410 through 12 gauge. Automobile accidents caused four of the blunt trauma injuries. The remaining blunt trauma injury resulted from vigorous jumping of a companion on the abdomen of the victim. Other objects causing trauma included impalement with fence stakes, pieces of glass and a sharp iron rod. Ingested foreign bodies causing injuries to the colon were a chicken bone and a toothpick.

Table I
MECHANISM OF INJURY

Mechanism	No.
Bullet	94
Knife	57
Shotgun	24
Blunt trauma	5
Varied objects (sticks, rods)	4
Ingested foreign body	2
Total	186

MANAGEMENT

Preoperative management consisted of the usual preparations for emergency surgery in acute abdominal trauma. Venesection by large bore needles, and surgical cutdowns were performed in the upper extremities for rapid restoration of blood volume and electrolyte equilibrium. Dextran was used as a plasma expander when rapid replacement was imperative. When dextran was used, no more than 1,000 ml. was given because of the danger of clotting disturbances. Saline solution was used as the non-colloidal fluid, and an average of 2,200 ml. of blood was given before and during the various operative procedures. Tetanus antitoxin or toxoid according to the individual indication was given in the receiving ward. Antibiotics were started as soon as possible. Nasogastric suction was utilized to evacuate stomach contents, often consisting of recently ingested alcoholic fluids. An indwelling urinary catheter was routinely inserted both to check for the presence of gross hematuria indicating injury to the urinary tract and to follow urine volume as a guide to fluid and blood replacement. Careful history and complete physical examination were performed to determine the probable site and extent of damage. Proctoscopy was performed in lower abdominal injuries when trauma to the rectosigmoid region was suspected. Roentgenographic examination of the thorax and abdomen was performed to further trace the course and location of the missile. However, in some cases bleeding was so massive that exploration was performed before such diagnostic procedures could be obtained.

Operative management consisted of the rapid exploration of the patient through a midline abdominal incision. After significant hemorrhage was controlled, injuries to the colon were repaired by two-layer closure technic turning in generous amounts of large bowel wall. When the colon was badly damaged, segmental resection was performed with end-to-end anastomosis. Exteriorization was used in cases in which long segments of bowel had been destroyed making repair difficult. Proximal colostomy was used in low rectal lesions and in some cases of massive destruction of long segments of bowel. Thorough irrigation with saline and antibiotic solutions was performed during the procedure and immediately prior to closure of the abdominal wall. Drains were usually placed near the area of injury and brought out through the abdominal wall laterally.

RESULTS

Over-all mortality for the 186 patients was 13.9 per cent. Primary repair was employed in 144 patients, with ten deaths, a mortality rate of 7 per cent. (Table II.) In fifty-three patients with knife injuries repaired primarily there was only one death, a mortality rate of 2 per cent. Primary repair was performed in eighty-one firearm injuries with eight deaths, a mortality rate of 10 per cent. There was one death from blunt trauma in the ten patients repaired primarily.

Two-stage repairs were performed in thirty-nine patients with twelve deaths, a mortality rate of 30 per cent. Colostomy was performed in nine patients with low rectosigmoid lesions with no deaths. In the thirty remaining patients, twenty exteriorizations and ten proximal colostomies were performed for massive destruction of large segments of the colon. Firearms inflicted the damage in twenty-five of these patients and accounted for all the deaths in this group. Two lacerations were treated by repair and diverting colostomy, and two by exteriorization. One case of blunt trauma was treated by repair and diverting colostomy.

Comparison of mortality rate between different types of repair is not justified in this series since the type of repair to be employed was determined by the severity and extent of injury to the bowel. Thus higher mortality would be expected in the more severely injured patient treated with the two-stage procedure.

Comparison of the type of repair and results for the first seven years versus the last three years of this study shows an increasing proportion of the patients being managed by primary

TABLE II
TYPE OF TREATMENT AND RESULTS

Type Repair	Inflicting Agent	Cases (No.)	Deaths (No.)	Mortality (%)
Primary	Firearms	81	8	10
	Knife	53	1	2
	Other	10	1	10
Two-stage exteriorization	Firearms	18	7	39
	Knife	2	0	0
Repair and proximal colostomy	Firearms	16	5	31
	Knife	2	0	0
	Other	1	0	0

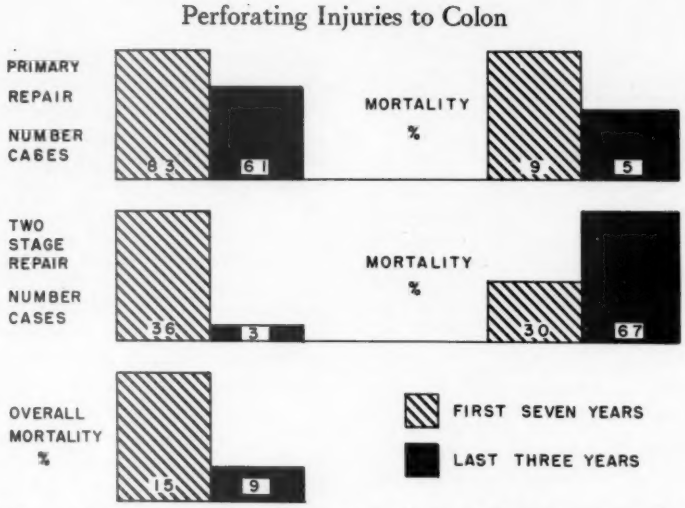

FIG. 1. Comparison method of repair and results for the first seven versus the last three years of study.

repair. (Fig. 1.) Mortality for primary repair has dropped from 9 per cent to 5 per cent and the over-all mortality has decreased from 15 per cent to 9 per cent. Average hospital stay for primary repair of the colon was fourteen days while an average of thirty-five days was required with the two-stage procedure.

FACTORS INFLUENCING RESULTS

Interval from Injury to Surgery. The average time interval elapsing from injury until admission to the receiving ward was 1.2 hours. Operative treatment was started an average of 2.8 hours after injury. Others have stressed the importance of early operation pointing to superior results in the patients who underwent exploration within six hours of the injury [*13, 14*]. Seven patients in this series had a delay of more than six hours between injury and operation, yet there was no mortality nor significant morbidity in this group.

Associated Injuries. There were 272 major organs injured in this series exclusive of injuries to the colon and averaged 1.5 injuries per patient. (Table III.) In forty-three patients without associated injuries (23 per cent), there was no mortality and only one complication, a single fecal fistula. Patients who did not survive had an average of five major organs involved.

Age. In patients over fifty years of age the mortality rate was 46 per cent indicating that with increasing age, tolerance for major trauma markedly declines [*4*]. Not only does arteriosclerosis make hemorrhage difficult to control, but it also makes the brain, heart and kidney vulnerable to periods of hypotension.

Blood Replacement. Although the average amount of blood administered was 2,200 ml., an average of over 5,000 ml. was required in

TABLE III
ASSOCIATED INJURIES

Injury	No.
Vascular injuries	
Heart	1
Aorta	2
Vena cava	8
Other major vessels	5
Total vascular injuries	16
Stomach	29
Ileum or jejunum	79
Duodenum	14
Spleen	17
Liver	37
Kidney or ureter	22
Central nervous system	4
Diaphragm	8
Chest (hemothorax)	4
Gallbladder	12
Pancreas	6
Bladder and urethra	5
Uterus	3
Extremities	16
Total	256

TABLE IV
COMPLICATIONS

Wound infection	12
Wound dehiscence	7
Fecal fistula	7
Acute renal failure	7
Intestinal obstruction	5
Abscess	3
Jaundice	2
Duodenal fistula	2
Urinary fistula	2
Biliary fistula	1
Pneumonia	1
Pulmonary embolism	1
Osteomyelitis of sacrum	1

those patients that died. No patient receiving more than 10,000 ml. of blood survived. Four deaths in this series resulted from hemorrhage and two patients died because of disturbances in the clotting mechanism. There were eight cases of acute renal failure. No doubt some of these complications resulted from massive blood transfusions necessary to sustain life.

COMPLICATIONS

Wound infection and dehiscence were the most common complications. (Table IV.) Fecal fistula occurred in seven patients with six fistulas closing spontaneously, and in the seventh patient death resulted from multiple complications. Intra-abdominal abscess was surgically drained in three instances.

CAUSE OF DEATH

Hemorrhage, irreversible shock (with death occurring within forty-eight hours of the injury), renal failure and peritonitis caused twenty of twenty-five deaths. (Table V.) Seven deaths were related to the injury to the colon directly, six patients dying from peritonitis and one from fecal urinary fistulas. Of the six deaths occurring in the last three years of the present study, three were caused by irreversible shock, two by renal failure and the remaining death by peritonitis.

TABLE V
CAUSE OF DEATH

Hemorrhage	4
Shock	6
Peritonitis	6
Renal failure	4
Fecal and urinary fistula	1
Duodenal fistula	1
Pneumonia	1
Pulmonary embolism	1
No demonstrable cause	1
Total	25

COMMENTS

There is no doubt that routine exteriorization of all traumatic injuries to the colon in the early phases of World War II resulted in increased survival rates. However, by late 1944, military surgeons in some theaters of operation were performing primary repair of selected injuries to the colon with equally good results yet decreased hospitalization time [*10*]. Nevertheless, in the immediate postwar period, exteriorization or primary repair and diverting colostomy remained the dominant method of treatment of injuries to the colon. Woodhall and Ochsner [*14*] pointed out that routine use of this form of therapy resulted in increased hospitalization time and needless second operations, and further noted that this treatment was applied "too wholeheartedly for the good of the patient."

Marked differences exist between most civilian and military injuries to the colon. Approximately 75 per cent of battlefield injuries are caused by fragmentation missiles, resulting in wounds with massive destruction of tissue. Many of the remaining war injuries result from high velocity missiles which cause large colon defects with surrounding zones of devitalized tissue. High velocity civilian injuries to the colon are rare and usually result from missiles discharged from big game rifles or special pistols of law enforcement officers. Shotgun injuries, especially when inflicted at close range, have a similar degree of destruction. These injuries with massive bowel destruction in which restoration of continuity is difficult should be treated by two-stage repair.

The majority of civilian injuries to the colon are limited in extent and can be managed best by simple closure or resection with end-to-end anastomosis. Injuries to the extraperitoneal rectum should be treated by repair and diverting colostomy.

SUMMARY

The present study is an analysis of the surgical treatment of 186 traumatic lesions of the colon. Primary repair without colostomy

was employed as the definitive operation in 144 patients with a mortality of 7 per cent. Two-stage procedures were used in thirty-nine patients with a mortality rate of 30 per cent. Overall mortality in this series was 13.9 per cent. Hospitalization stay averaged only fourteen days in patients with primary repair and thirty-five days when the two-stage procedure was used. Significant factors in mortality were advanced age, multiple organ injuries and massive transfusion. Primary repair without colostomy is the treatment of choice in civilian injuries to the colon. Exteriorization or diverting colostomy is reserved for lesions with massive destruction of the colon and in lesions of the extraperitoneal rectum.

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Non-penetrating Injuries to the Spleen

D. Economy, M.D., C. Koucky, M.D. and R. L. Novack, M.D., *Detroit, Michigan*

Death is frequently cased by traumatic injury to the spleen, and immediate splenectomy is generally accepted as a curative procedure which can be performed with minimal mortality. We suspect that the frequent failure to diagnose this condition has a direct influence on the number of deaths caused by it. Even minor hemorrhage from a traumatized spleen rarely subsides spontaneously and the mortality rate approaches 100 per cent when diagnosis and treatment are delayed. To aid in the discussion as to how this condition can be recognized, we have reviewed herein a consecutive series of sixty cases of blunt traumatic injury to the spleen. These patients were treated at Detroit Receiving Hospital and Providence Hospital in Detroit during the years 1953 through 1957.

In the group studied, the youngest patient was five and a half months old and the oldest was seventy-one. However, the highest incidence of these injuries occurred in the first decade of life. Other authors [*1,4*] have reported the highest incidence in the second to the fourth decade of life. The ratio of males to females was about three to one. (Fig. 1.)

The majority of splenic injuries follow violent trauma, although minor or even insignificant trauma may rupture a normal spleen. Three patients who were not included in this series had a ruptured spleen without a history of any antecedent external injury. The precipitating factor was coughing in one patient, and vomiting in another. Approximately 80 per cent of splenic injuries in this series were caused by auto accidents. These were equally divided between pedestrians and passengers. (Fig. 2.)

Most symptoms referable to a ruptured spleen are those due to blood loss and peritoneal irritation produced by this blood. Furthermore, the severity of these symptoms is proportional to the extent of damage to the spleen and the amount of associated hemorrhage. Associated injuries, which occurred in 75 per cent of the patients in this series, can alter or obscure the symptoms of splenic injury. Pain in the lower left side of the chest, which is often present in patients with splenic injury, may be difficult to differentiate from the pain in the upper left quadrant caused by peritoneal irritation. Intercostal block may help clarify the origin of the pain by abolishing the pain in the thoracic wall but not the pain of peritoneal irritation. Only four patients complained of pain referred to the left shoulder. This is in contrast to other

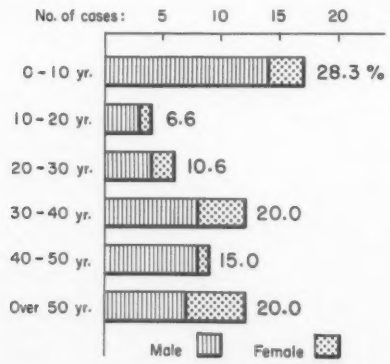

Fig. 1. Age group.

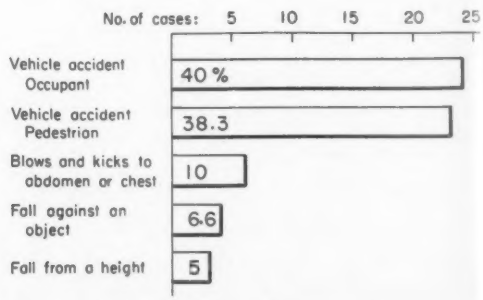

Fig. 2. Type of trauma.

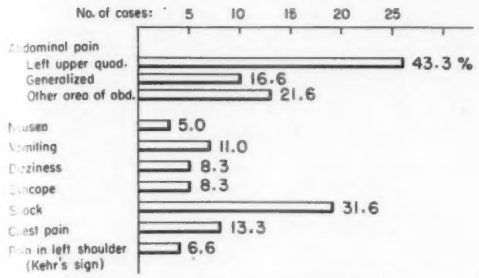

FIG. 3. Symptoms found in patients with ruptured spleen.

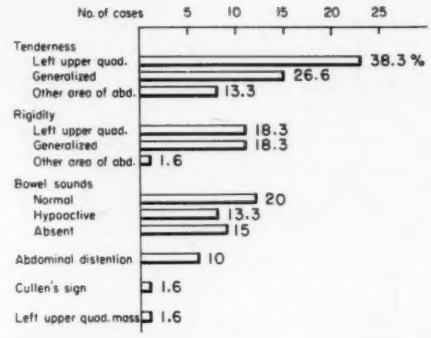

FIG. 4. Signs found in patients with ruptured spleen.

reported series [1–6] in which emphasis was placed upon its presence in splenic injury. We have found that the existence of Kehr's sign may be suggestive of splenic injury but its absence does not exclude it. (Fig. 3.) Physical signs can also be correlated with the amount of splenic damage. Bleeding confined to the area of the left upper quadrant of the abdomen will give most pronounced signs at this site, while massive bleeding into the peritoneal cavity will produce more generalized abdominal findings. Over 65 per cent of the patients had audible bowel sounds although the peritoneal cavity contained large quantities of blood. (Fig. 4.)

Other authors [4] mention the value of paracentesis as an aid in the diagnosis of intraperitoneal hemorrhage; however, some writers persistently condemn this simple but extremely beneficial diagnostic measure. This procedure was performed on forty-seven patients, and in 83 per cent free blood was aspirated from the peritoneal cavity. (Fig. 5.) A second paracentesis often demonstrated the presence of free blood in the peritoneal cavity when the first one had not. In many of the cases, aspiration was performed in only one of the four quadrants of the abdomen. In some cases no blood was found in paracentesis of the left upper quadrant, whereas blood was present in other quadrants. Therefore, we emphatically advocate paracentesis of all four quadrants of the abdomen prior to concluding that free blood does not exist in the greater peritoneal cavity. The presence of free blood in the peritoneal cavity is not pathognomonic of a ruptured spleen since it can occur secondary to a rupture of any solid or hollow viscus. It is, however, indication for immediate operative intervention.

Of equal significance is the fact that there was not a single complication from the procedure in the forty-seven cases in which paracentesis was performed. It is certain that in most instances of questionable diagnosis, the aspiration of gross blood from the peritoneal cavity was most instrumental in early operative intervention.

Although recognizable damage to the left kidney was seen at exploration in only 13 per cent of the cases, blood was found in the urine specimens taken on admission in 51 per cent. Similarly 65 per cent of the patients had albuminuria on admission. (Fig. 6.)

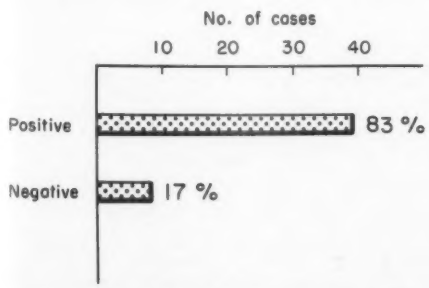

FIG. 5. Results of abdominal paracentesis.

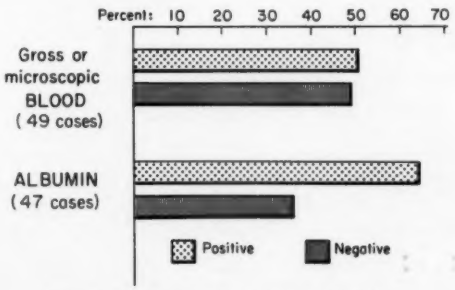

FIG. 6. Results of urinalysis on admission.

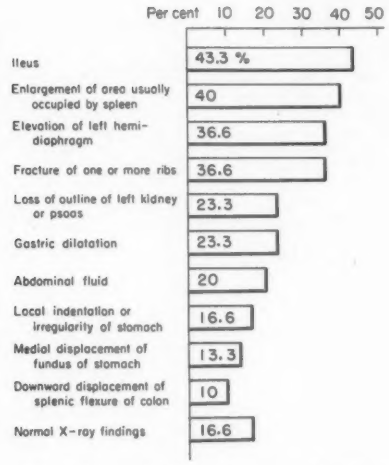

FIG. 7. X-ray findings in rupture of spleen.

Hemoglobin levels and leukocyte counts on admission were too variable to be dependable. A persistent decline in the hemoglobin level and/or a rise in the leukocyte count was of greater value in suggesting the presence of splenic bleeding when laparotomy was not immediately performed.

Although not conclusive, roentgenograms of the abdomen can be helpful in the diagnosis of a ruptured spleen; however, they revealed no abnormality in many of the cases in our series. The most specific and useful findings are those suggesting a mass in the left upper quadrant with displacement of adjacent organs. (Fig. 7.) Those findings suggesting generalized abdominal fluid and its secondary effect upon the bowel, namely ileus, are less specific.

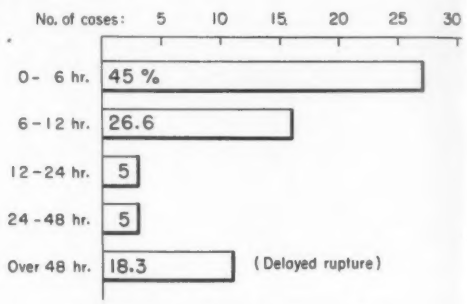

FIG. 8. Interval from trauma to surgery.

The interval between injury and the time of splenectomy undoubtedly depends on the degree of splenic damage. Laparotomy was carried out within six hours in 45 per cent of the patients and within twenty-four hours in 75 per cent of them. (Fig. 8.) When the bleeding was less profuse, or the physical findings less conclusive, longer delays were encountered. In approximately 20 per cent of the cases, exploration was deferred longer than forty-eight hours following injury. The classic picture of delayed rupture associated with abrupt onset of weakness, syncope and shock was seldom encountered. A gradual fall in the hemoglobin level or an increase in severity in abdominal pain was more frequently observed.

Splenectomy was always performed through a left subcostal incision. Free blood was encountered in all cases when the peritoneal cavity was opened. The extent of splenic damage varied. Many patients had severe lacerations of the spleen or its pedicle with profuse bleeding. In others the bleeding had subsided

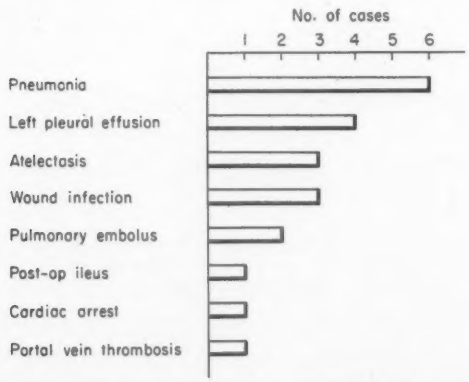

FIG. 9. Injuries associated with ruptured spleen.

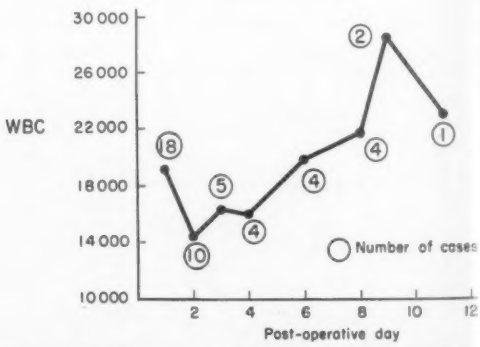

FIG. 10. Rib fractures associated with ruptured spleen.

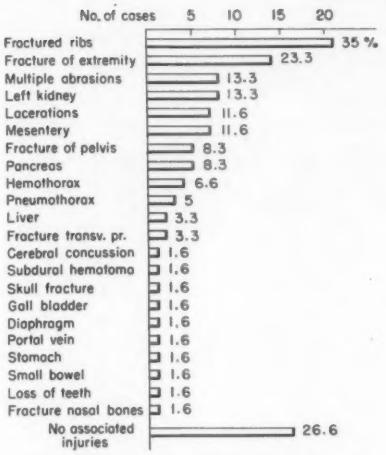

FIG. 11. Complications of splenectomy.

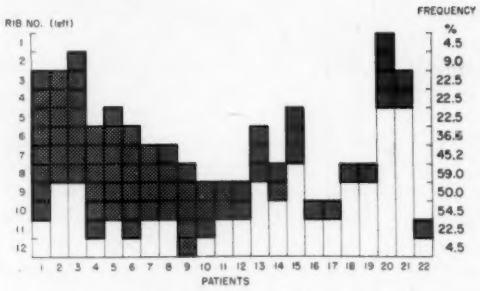

FIG. 12. Peak postoperative white blood count.

and the spleen was buried in a thick network of clots. The most commonly associated intra-abdominal injury was contusion of the left kidney. Mesenteric tears were not infrequent. In two instances minor lacerations of the liver were found. The associated intra-abdominal injury may be more severe than the ruptured spleen as illustrated by a patient who had a laceration of the portal vein and the superior mesenteric artery. Thorough exploration of the abdomen for coexistent trauma is imperative.

Associated injuries were present in 75 per cent of the patients. About one-third had rib fractures on the left side and an equal number had other skeletal fractures. (Fig. 9.) The eighth rib on the left side was the most frequent site of fracture. (Fig. 10.) Approximately 75 per cent of those patients with a fractured eighth rib had adjacent rib fractures.

Postoperative complications attributable to splenectomy alone occurred in nineteen patients. (Fig. 11.) Pulmonary complications comprised 72 per cent of the total. This is no doubt due to the frequency of associated contusions of the chest wall, fractures of the ribs, and the location of the abdominal incision. Two patients died from pulmonary emboli, one on the seventh and the other on the thirtieth postoperative day. Although there is no certainty that these emboli were related to thrombocytosis due to the splenectomy, one should be aware of this potential relationship which has been encountered by others. Wound infection occurred in only three cases, which suggests that there is no alteration in the speed of wound healing or the degree of resistance to infection following splenectomy. None of the patients experienced postoperative hemorrhage, gastric or pancreatic fistulas, or clinically detectable pancreatitis.

It has been recognized that leukocytosis follows splenectomy. The reason for this is not clearly understood at the present time. If this response does occur, hospitalization may be prolonged on the assumption that operative complications may exist. (Fig. 12.) The highest platelet count encountered postoperatively was 630,000 per cu. mm. which appeared on the twelfth postoperative day. Others have reported counts of more than 1 million associated with thrombotic episodes.

The morbidity following splenectomy in patients who had no associated injuries was relatively short. Seventy-four per cent of the patients were discharged by the tenth hospital day and all were discharged by the fourteenth day. Prolonged hospitalization was necessary only for those patients who had other serious injuries. The over-all mortality in the sixty patients who sustained a traumatic injury to the spleen was 10 per cent. All, except one of the patients who died, had an associated injury.

SUMMARY

Rupture of the spleen is encountered in all age groups, it may follow trauma of varied severity, and is associated with a wide variety of other injuries. Symptoms and signs may range from negligible to severe, and may be abrupt or late in onset. Wide variations in the initial leukocyte counts and hemoglobin levels are encountered.

Paracentesis is the most important diagnostic procedure for determining the presence of intra-abdominal bleeding. The presence of blood on paracentesis in a patient who has sustained trauma to the upper portion of the abdomen is an indication for immediately exploring the abdomen. If the paracentesis reveals the absence of free peritoneal blood and the patient shows signs of progressive loss of blood, peritoneal irritation, a rising leukocyte count and a decline in the hemoglobin values, celiotomy is indicated.

The mortality from splenectomy is low, but it rises in proportion to the extent of associated injuries.

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Portal Hypertension as the Result of Penetrating Abdominal Trauma

T. B. Patton, M.D., *Birmingham, Alabama,* and C. G. Johnston, M.D., *Detroit, Michigan*

It is now generally conceded that in man acute ligation of the portal vein, while not a desirable practice, is compatible with life. As recently as 1938, it was categorically stated that acute ligation of the portal vein was fatal in animals (excluding fowls) and humans alike [*4,11*]. As our basic concepts of the pathologic physiology of trauma, fluid and electrolyte balance, and use of antibiotics have improved, acute ligation of the portal vein has been performed in major surgery for cancer [*8*] and in treatment of trauma to this structure as a result of penetrating wounds of the abdomen.

The sequelae following acute ligation of the portal vein associated with emergency splenectomy are not well understood. It is the purpose of this report to present two cases in which emergency suture of the portal vein and splenectomy were necessitated by gunshot wounds of the abdomen.

The clinical course of these patients was characteristic of extrahepatic portal hypertension, and they ultimately required portasystemic shunts to control massive hemorrhage from esophageal varices. The management and optimal time for shunting in these patients are to be presented and discussed.

CASE REPORTS

Case 1. J. McF., a thirty-one year old Negro man, was wounded with a .45 caliber bullet on November 23, 1939. He was admitted to the hospital and underwent exploration. At this time, in addition to other injuries, he had a large hematoma, in the right side of the abdomen. This was explored and massive hemorrhage ensued. Control was obtained and the inferior vena cava was believed to be the source of the hemorrhage. The patient eventually recovered and left the hospital. However, he had two episodes of massive bleeding within the first year postoperatively. For the next eight or nine years, bleeding episodes requiring massive replacement of whole blood and esophageal tamponade occurred every year. He refused to undergo any type of shunt operation during this period. The bleeding episodes subsided for the next five years probably because of build-up of collaterals. In 1953 he was readmitted to the hospital because of massive bleeding of the upper gastrointestinal tract. At this time he did not complain of

Fig. 1. Case 1. Varices in the lower third of the esophagus.

FIG. 2. CASE I. Splenoportogram.

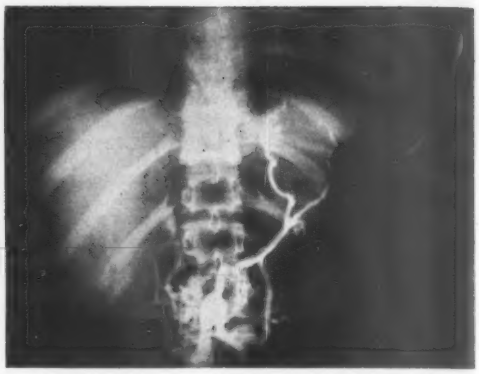

FIG. 3. CASE II. Operative portogram.

any pain or enlargement of the abdomen. A fluid wave was detected. Hematemesis and tarry stools were present throughout his hospital course. Esophageal varices were demonstrated by a barium swallow test. (Fig. 1.) No portal vein was demonstrated on exploration or by the portagram which was performed at the time of operation. (Fig. 2.) A shunt was constructed between a large coronary vein and the inferior vena cava. He had a stormy postoperative course during which intestinal obstruction developed for which he was reoperated upon and recovered completely. Ascites was present for a time. The patient has had no further incidence of hematemesis or melena since operation.

CASE II. F. S. (No. E2,503) was a seventeen year old white boy who was wounded on December 19, 1958, by a .22 caliber bullet. The point of entrance was in the left flank with an upward traverse, and the point of exit was in the posterior axillary line on the lower right side of the chest. He was immediately taken to the hospital, and underwent exploration. Splenectomy and repair of lacerations of the stomach, liver and pancreas were performed. Suture of a rent at the junction of the splenic and superior mesenteric veins involving only the anterior wall was performed. He was discharged three weeks postoperatively although he had not regained his strength and had lost about 30 pounds. On March 9, 1959, he experienced generalized abdominal pain and a feeling of fullness which was not relieved by the usual measures. Hematemesis and melena followed and continued intermittently until his admission to the University Hospital on March 17, 1959.

On admission blood pressure was 180/62 mm. Hg and pulses were irregular and paired. The patient was undernourished and apathetic and appeared anxious and fretful. The sclerae were mildly jaundiced and the heart was markedly enlarged about 2.5 cm. to the left of the midclavicular line with a marked thrill over the point of maximum pulsation. Lungs were clear and resonant. There was a well healed midline surgical scar and the liver was palpable three fingerbreadths below the right costal margin with a sharp border. No bruits were heard on auscultation, and peristalsis was hyperactive. Genitalia were normal and rectal examination revealed good sphincter tone and tarry material on the gloved finger. There was no edema of the extremities or dilatation of the superficial veins. Diagnosis at this time was portal hypertension due to ligation of the splenic and portal veins or hemobilia, with rheumatic heart disease and mitral stenosis and insufficiency.

Studies of the patient were performed over the next ten days. Liver functions were normal, and no varices were seen on barium study. He continued to bleed and have abdominal pain.

On March 27, 1959, he underwent exploration. Dense, vascular adhesions in the abdomen were cleared from the right free border of the gastrohepatic omentum. With the palpating finger in the foramen of Winslow, the portal vein could be identified as a hard fibrous cord. Aspiration of the gallbladder did not reveal any old or recent blood. Portal pressure measured in a secondary branch of a jejunal vessel was in excess of 60 cm. of saline solution. A portagram showed obliteration of the splenic and portal veins. (Fig. 3.) A shunt was performed in side-to-side fashion between a secondary radicle of the superior mesenteric vein and the inferior vena cava using intima-to-intima approximation. (Fig. 4.) His postoperative course was uneventful. He was discharged on April 6, but returned on April 19, after vomiting approximately 5 cc. of blood. Moreover, massive melena was present. On admission, temperature was 104°F. and blood cultures were taken. Staphylococcus aureus, coagulase positive, was present but sensitive to all antibiotics. Under an antibiotic regimen

he patient improved rapidly. The bleeding episode as attributed to the small size of the shunt. (We elieve that as collaterals form, the shunt and ollaterals will prevent further bleeding episodes.) ile was discharged and this was attributed to a epatodiaphragmatic bronchial fistula which subided on postural drainage. The patient was discharged on May 7, and since that time has had rther bleeding episodes but has gained markedly weight and strength.

ETIOLOGY

Thrombosis of the portal vein has been well documented. It is described as a complication of debility without basic liver disease [7]. A number of cases have been reported in which portal thrombosis has occurred following falls, kicks or relatively insignificant trauma to the abdominal wall [24,26]. It is reported as a consequence of splenectomy for primary splenic disease [10] or the incidental removal of the spleen at the time of surgery for malignancies of the stomach or colon.

For the purpose of this discussion we are considering only those patients without basic liver disease who require acute ligation of the portal and splenic veins as a result of misadventure. When acute ligation of these structures is performed normal drainage of the portal system is prevented or impeded without diminution of arterial inflow. The consequent thrombosis of these two major radicles of the portal system results in extrahepatic portal hypertension with the expected build-up of an inadequate collateral portasystemic circulation. Esophageal varices develop as a reflection of increased portal pressure, bleed massively, and continue as a threat to life. Survival through many such bouts is due in part to massive replacement of whole blood, but more importantly to a normal liver which does not complicate the period of acute hemorrhage by faulty metabolic activity leading to episodic stupor.

As a reflection of impedance to portal flow, portal hypertension due to penetrating abdominal trauma differs in no way from extrahepatic portal hypertension caused by portal thrombosis due to differing poorly understood etiologies [13] and, indeed, the diagnosis and treatment are identical.

CLINICAL PICTURE

Patients with gunshot wounds of the abdomen require emergency surgical operation.

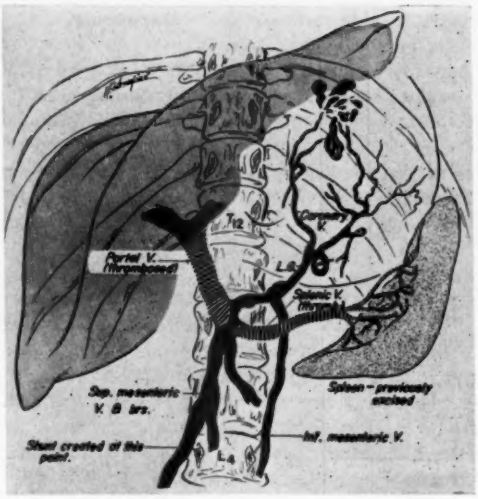

FIG. 4. CASE II. Line drawing of portogram.

After the abdomen is opened, one is usually confronted with a large amount of blood in the peritoneal cavity. The first and best identified injury is trauma to the spleen which is removed with dispatch, and the peritoneal cavity is hastily mopped out. At this time blood is seen leaking into the peritoneal cavity through a rent in a large retroperitoneal hematoma usually on the right side of the abdomen. A guddling exploration of this hematoma releases a gush of blood and precise identification of the bleeding point is difficult. After frantic maneuvers consisting of pressure and application of hemostats, bleeding is controlled with no certainty of the vessel involved. It is usually thought to be the inferior vena cava. (This was the conclusion reached in Case 1 presented herein.) After a tedious convalescence the patient usually recovers. Massive upper gastrointestinal bleeding usually occurs within three months after the operation. This may be painless or may be introduced by severe bouts of generalized or epigastric pain. There may be minimal hematemesis and massive melena or massive hematemesis. The patient is thin, pale and apathetic, appearing chronically ill. He has not had the expected weight gain in the postoperative period and also complains of marked fatigue on minimal exertion. These patients usually complain of abdominal pain which has no relation to food intake, position or activity, and there is usually no

response to the usual ulcer management. On examination, there is usually no marked enlargement of the liver, but the abdomen feels doughy on palpation and a collateral plexus of veins may be seen coursing over the abdomen and extending up over the lower anterior part of the chest. A low grade febrile course may also serve to further confuse the picture.

DIAGNOSIS

With such a paucity of findings, a correct diagnosis is difficult unless considered carefully. Liver function studies are normal. None of the stigmata of liver disease are present and the spleen, which by its enlargement would be the best indicator of increased pressure in the portal system, is gone [*15*]. The most rewarding diagnostic procedure during an episode of acute hemorrhage is tamponade [*20*]. Bleeding, if from varices, will be controlled and may lead one to consider portal hypertension as the cause of the hemorrhage. Following control of bleeding the upper gastrointestinal series may or may not reveal varices; however, if performed four to six weeks after bleeding has subsided, the demonstration of varices is rendered easier because of the reaccumulation of pressure in the portal system. With the demonstration of varices the correct identification of the bleeding vessel at the time of the initial operation may become apparent in that it was probably the portal vein and not the inferior vena cava that was injured. This impression may further be enforced by the lack of distention of the superficial veins and the lack of edema in the extremities which usually accompanies ligation of the inferior vena cava.

DIFFERENTIAL DIAGNOSIS

The chief condition to be considered here is hemobilia [*17,25*]. This may be the source of massive and confusing bleeding following any injury to the liver and, indeed, usually makes its appearance at about the same time after the initial exploration [*27*]. Bleeding originates from the necrotic area of injury in the liver and finds its way into the gastrointestinal tract by way of the common duct. Intrahepatic-artery aneurysm either as a result of trauma or spontaneously formed may also cause hemobilia [*16*]. The other reported cause of hemobilia is acute necrotizing cholecystitis [*28*]. This may be an unwelcome but spontaneous complication following any exploration. These diagnoses should be the chief differentials to be considered but may be excluded preoperatively by the finding of varices when a barium swallow test is performed.

Other conditions to be considered are pancreatic fistulas and peptic ulcerations. Pancreatic fistulas usually result from injuries to the pancreas overlooked at the time of the original exploration. The low grade inflammation in proximity to the stomach fosters gastritis and bleeding. These patients usually have an elevated serum amylase level and feel better when the stomach is empty or nearly so. A meal of any proportion will usually precipitate pain or bleeding. Peptic ulcers of the stomach or duodenum as a result of long continued stress may be considered but can usually be excluded by the negative gastrointestinal series.

TREATMENT

These patients should undergo re-exploration to identify the precise mechanism causing hemorrhage. The true nature of the underlying difficulty is readily apparent when the abdomen is entered, and one encounters the vascular adhesions and notes the dense portal collateral over the parietal peritoneum. Dissection is tedious and difficult for every capillary bleeds: however, if adhesions can be cleared from the right free border of the gastrohepatic omentum, an exploring finger placed in the foramen of Winslow will palpate the hard, cord-like thrombosed portal vein. Measurements of portal pressure will reveal abnormal levels in the portal system. Operative portograms will not reveal the portal or splenic veins. The best site for construction of a "makeshift" or secondary portacaval anastomosis will be demonstrated by the portogram. This "makeshift" anastomosis will usually have to be performed at the level of the superior mesenteric vein or between a dilated collateral in the right free border of the gastrohepatic omentum. It is useless to use a collateral which is less than 1 cm. in diameter. We use a side-to-side anastomosis [*22*] of the secondary radicle with the inferior vena cava with intima-to-intima approximation [*3*]. A shunt was performed between the coronary vein and the inverior vena cava on one patient and between a secondary radicle of the superior mesenteric vein and the inferior vena cava on another.

After the shunt is opened the troublesome bleeding apparent all during the procedure stops. Biopsy of the liver is performed and the abdomen closed.

PROGNOSIS

A shunt usually benefits these patients. Bleeding is no longer a problem and they rapidly gain weight and strength. Prognosis should be guarded, however, for it should be remembered that these shunts are of the "makeshift" variety and if closure ensues, bleeding will probably recur. Of further ominous import are the reported cases of mesenteric venous occlusion following thrombosis of the portal vein [*2,29*].

COMMENTS

It was originally thought on the basis of previous experimental work that acute ligation of the portal vein was not compatible with life [*14*]. Pick [*23*] and later Neuhoff [*19*] were among the first to point out that collaterals in the gastrohepatic omentum could accomplish a readily available portasystemic anastomosis. In 1948 Milnes and Child [*18*] acutely ligated the portal vein in the Macacus Rhesus monkey successfully.

Earlier scattered operative case reports [*18*] lent support to the concept that acute ligation of the portal vein could be safely performed when (1) portal flow was not completely occluded [*5,6*], and (2) the character of the lesion fostered portal collaterals prior to the time of operative intervention [*9*].

In the two cases presented herein, the portal and splenic veins were acutely ligated which not only interfered with portal return but also obliterated many channels of anastomotic return because of consequent thrombotic extension from these ligated vessels. The cause of bleeding in these patients would appear to be substantiated by Abeatici's [*1*] postulate using the Hagen-Poiseuille equation:*

$$V = \frac{\pi R^4}{8NL} p^1 - p^2$$

* V = Volume.
R = Radius of vascular diameter of the portal arc.
N = Intrinsic coefficient of fluid.
L = Length.
$p_1 - p_2$ = Difference in pressure propelling the fluid.
π = Time.

It was his conclusion that portal hypertension *per se* would cause no bleeding from the gastrointestinal tract. It would occur promptly, however, when stasis developed in the system [*1*]. This may well explain the hemorrhage from the gastrointestinal tract (stomach and small bowel) preceded by pain, meteorism and diarrhea. Ligation of the splenic and portal veins almost synonymously does cause marked stasis in the portal system with no diminution of arterial inflow.

It is further suggested that at the time of laparotomy for gunshot wounds of the abdomen every effort should be made to delineate the precise source of hemorrhage. Hemobilia, while not reported as a consequence of a gunshot wound of the liver, must be considered as one of the rarer sources of occult hemorrhage of the upper gastrointestinal tract. This consideration prompted aspiration of the gallbladder in Case II. It is necessary to mobilize the duodenum adequately, using the Kocher maneuver, not only to evacuate the hematoma in the area but also to adequately visualize the portal vein. One should not forget the information which may be provided by compression of the portal triad through the foramen of Winslow. This may arrest the hemorrhage sufficiently to visualize the rent in the portal vein and meticulously close it [*12*]. This accurate suture will perhaps in most instances cause only partial occlusion of the lumen of the vein and lessen the possibility of gastrointestinal hemorrhage postoperatively. The other maneuver is simply manual compression of the inferior vena cava against the vertebral column, again at the level of the foramen of Winslow.

Even with accurate closure of the tear in the portal vein there may well be extension of the thrombus into the superior or inferior mesenteric veins, either from the suture line or microscopic areas of trauma in the wall of the damaged vessel.

It is our opinion that patients should undergo re-exploration in six weeks when they have penetrating trauma to the abdomen with massive bleeding not precisely identified at the time of the initial operation, when the portal vein or liver has been sutured or upper gastrointestinal hemorrhage occurs postoperatively. At the time of re-exploration, aspiration of the gallbladder or common duct should be performed to exclude hemobilia. Portal pressure should be measured and portograms performed.

Portograms will not only reveal the state of patency of the portal system but will also permit the identification of portal radicles large enough to be of use in constructing secondary or "makeshift" side-to-side anastomoses with the vena cava. By so doing, abnormal pressure in the portal system is effectively controlled, and repeated hemorrhage of the upper gastrointestinal tract will not threaten these patients [*21*].

CONCLUSIONS

1. Two cases of gunshot wounds of the abdomen with concomitant trauma to the spleen and portal vein are presented.

2. Acute ligation of the portal and splenic veins is compatible with life, but hemorrhage from the upper gastrointestinal tract follows either from varices or congested gastrointestinal mucosa.

3. A course of management and a method of treatment are proposed.

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Indications for Operation in Abdominal Trauma

GERALD W. SHAFTAN, M.D., *Brooklyn, New York*

From the Department of Surgery, State University of New York Downstate Medical Center, 450 Clarkson Avenue, Brooklyn, New York.

IN general, traumatic wound therapy in civilians follows military practice. After World War II it was inevitable that the war time management of abdominal wounds should carry over into the peace time emergency rooms and operating theaters. The military practice of routinely performing early exploration was based on the almost uniformly fatal outcome of non-operative treatment of patients with intraperitoneal injuries [*1*]. The reduction of this rate was directly proportional to the reduction in the time interval between occurrence of the wound and repair [*1,2*]. Bowers [*3*] epitomized this policy of early surgery, "With penetrating abdominal wounds . . . the question is not if we should operate but when."

Routine early operation in abdominal trauma was carried out in our hospital in the early 1950's. In the period from 1952 to 1954, 133 patients with abdominal trauma were treated. In 75 per cent of these the injuries were of the penetrating type. (Table I.) Spreng [*4*], in an unpublished review of these cases, found that in seventeen of eighty-eight patients who underwent celiotomy there was no intra-abdominal injury. One patient died as a result of the exploration. Thirteen additional patients required no treatment at exploration; all these had liver injuries. Therefore, thirty patients or over one-third of those operated on did not require reparative surgery.

The patients were divided into three groups: *Group A* were patients who had evidence of intraperitoneal injury at operation or autopsy. *Group B* were patients who were treated without operation. *Group C* were patients who underwent celiotomy without findings of intra-abdominal injury.

The signs, symptoms and laboratory studies of these patients were correlated. (Tables II and III.) None of the patients in groups B or C had generalized, direct or rebound tenderness, abdominal muscular spasm or absent bowel

TABLE I
TYPE OF TRAUMA (133 PATIENTS, 1952–1954)*

Type of Trauma	No.	%	% Explored
Stab wound	88	66	53
Bullet wound	12	9	92
Auto accident	13	10	84
Falls	7	5	86
Other blunt	9	7	78
Total	137†	103	66

* After SPRENG, D. S., JR. [4].
† Four patients had combined trauma.

TABLE II
PERCENTAGE OF PATIENTS WITH ABDOMINAL SYMPTOMS (133 PATIENTS, 1952–1954)*

Symptoms	Group†		
	A	B	C
None	51	77	73
Local or regional pain	17	18	21
Generalized pain	27	6	6
Nausea, vomiting, hematemesis or proctorrhagia	20	0	0

* After SPRENG, D. S., JR. [4].
† A = Patients found to have visceral injury at operation or autopsy.
B = Patients treated but not operated upon.
C = Patients with no visceral injury found at operation.

TABLE III

PERCENTAGE OF PATIENTS WITH PHYSICAL FINDINGS (133 PATIENTS, 1952–1954)*

Findings	Group A	Group B	Group C
*Direct Tenderness**			
None	16	68	29
Local	14	18	50
Regional	30	14	21
Generalized	40	0	0
Rebound Tenderness†			
None	39	100	86
Local	6	0	0
Regional	20	0	14
Generalized	40	0	0
Spasm and/or Rigidity‡			
None	47	92	79
Local	2	0	7
Regional	20	8	14
Generalized	31	0	0
Bowel Sounds§			
Normal or hyperactive	36	100	90
Hypoactive	27	0	10
Absent	38	0	0

* Not recorded in 20 per cent.
† Not recorded in 45 per cent.
‡ Not recorded in 25 per cent.
§ Not recorded in 32 per cent.

sounds. In the main these patients had no abnormal abdominal physical findings. Therefore, if the ordinary criteria for an acute surgical condition of the abdomen had been used, exploration would have been avoided in all the patients in group C.

On the basis of Spreng's study the management of abdominal trauma was changed. Indications for operation became essentially the same as those used in general, non-traumatic, abdominal surgery. That is, peritoneal irritation evidenced by tenderness, rebound tenderness, spasm of the abdominal wall and/or reduced or absent peristalsis was considered of primary importance. Hematemesis, proctorrhagia or positive abdominal paracentesis became secondary substantiating signs.

TABLE IV

TYPE OF TRAUMA (180 PATIENTS, 1956–1958)

Type of Trauma	No.	%	% Explored
Stab wound	103	57	31
Bullet wound	9	5	55
Auto accident, pedestrian	18	10	28
Auto accident, driver or passenger	16	9	19
Falls	7	4	14
Other blunt	25	14	16
Miscellaneous	3	2	66
Total	182*	101	32

* Two patients had combined trauma.

METHODS AND MATERIAL

One hundred eighty consecutive patients with abdominal trauma admitted to the University Surgical Service and the Trauma Service of Kings County Hospital Center from January 1956 to December 1958, were studied. They ranged in age from two to ninety-one years; males predominated four to one. Two-thirds were Negro or Puerto Rican. Over 20 per cent of the patients were seriously intoxicated on admission. As a group they appeared to be of below average intelligence and were frequently belligerent, and often uncooperative both consciously and unconsciously. The operation, when indicated, was performed by the surgical house staff under supervision. Patients who were not operated upon were followed up closely by the house staff until there was no longer any question of intra-abdominal injury.

RESULTS

The type of trauma (Table IV) is unusual for a civilian institution [5]. Sixty-three per cent of the injuries were penetrating in type. Two patients had combined trauma having been stabbed and kicked in the abdomen. Neither underwent surgery. The patients were divided into groups as in the previous study and reviewed on the basis of history, abdominal examination, miscellaneous signs, laboratory findings, associated injuries, treatment and disposition.

TABLE V
PERCENTAGE OF PATIENTS WITH ABDOMINAL SYMPTOMS
(180 PATIENTS, 1956–1958)

Symptoms	Group		
	A	B	C
None noted or not recorded	18	29	25
Local or regional pain	26	45	58
Generalized pain	34	9	0
Nausea or vomiting	29	6	16
Hematemesis or proctorrhagia (confirmed)	8	0	0

History. History (Table v) *per se* was of little value in determining the need for exploration. Little significance could be attributed to abdominal pain, mode of injury, reported length of knife, direction of blow or history of nausea and vomiting. Hematemesis and proctorrhagia, however, were good indications of visceral injury [*6*].

Generalized pain was found more often in the operative group but was frequently misleading as in the following case.

H. R., a twenty-one year old Negro man, was admitted to the hospital on July 20, 1958, with multiple non-bleeding knife wounds of the abdomen and chest. In addition he had been kicked in the abdomen several times. He complained of generalized abdominal pain and there were episodes of vomiting and retching. Regional and rebound tenderness with muscular spasm were present in the left upper quadrant. Bowel sounds were normal. The patient was kept under observation. He continued to complain of abdominal pain until he was discharged one week later. He entered the hospital again on July 29, 1958, still complaining of generalized abdominal pain. After a week of observation failed to reveal any pathologic condition of the abdomen, he was discharged. On August 7, 1958, he was admitted to another service with a stab wound of the epigastrium and the same complaints of generalized abdominal pain. Physical signs were equivocal. Exploration failed to reveal penetration or intra-abdominal injury.

Abdominal Examination. Physical signs (Table vi) as expected were of greatest prognostic value. The absence of bowel sounds was the most reliable sign of visceral injury and the presence of them prompted conservative management.

TABLE VI
PERCENTAGE OF PATIENTS WITH PHYSICAL FINDINGS
(180 PATIENTS, 1956–1958)

Findings	Group		
	A	B	C
Direct Tenderness			
Not recorded	0	5	0
None	0	29	25
Local	18	40	58
Regional	29	21	0
Generalized	53	5	16
Rebound Tenderness			
Not recorded	18	20	8
None	18	62	58
Local	3	8	8
Regional	18	8	8
Generalized	42	1	16
Spasm and/or Rigidity			
Not recorded	10	11	8
None	13	64	67
Local	6	11	8
Regional	29	9	16
Generalized	42	1	0
Bowel Sounds			
Not recorded	0	6	0
Normal	12	69	58
Hyperactive	0	3	8
Hypoactive	42	8	25
Absent	47	0	8

G. A. was a nineteen year old Negro girl who had been severely kicked in the abdomen three hours before admission. When she entered the hospital she had diffuse abdominal pain which was accompanied by hematuria. There was diffuse abdominal tenderness with lower abdominal rebound tenderness and rigidity. Bowel sounds were normal. Tenderness was also present on rectal and pelvic examination. The patient was observed closely and was asymptomatic within twenty-four hours. She was subsequently discharged without further treatment.

J. A., a ten year old Negro boy, was struck by a car. At the time of admission he had diffuse abdominal pain. Direct and rebound tenderness with spasm was present in the lower part of the

TABLE VII
ASSOCIATED INJURIES

Injury	No.
Extremity fractures, closed	4
Extremity fractures, open	3
Pelvic fractures	5
Spine fractures	2
Thoracic cage injuries	15
Pleuropulmonary injuries	8
Cerebral injuries	9
Major soft tissue injuries	4
Minor soft tissue injuries	53

TABLE VIII
TREATMENT AND MORTALITY
(180 PATIENTS, 1956–1958)

Data	Patients		Mortality	
	No.	%	No.	%
Died before evaluation	2	1	2	100
Non-operative management	125	69	1	<1
Operated				
With visceral injury	40	22	8	20
Without visceral injury	13	7	0	...
Total	180		11	6

abdomen. Bowel sounds were normal. An abdominal roentgenogram showed a pattern of ileus. He was kept under observation and had an uneventful hospital course.

Miscellaneous Signs. The herniation of intraperitoneal contents was noted in seven cases. In one instance celiotomy was not performed. Intragastric blood or rectal bleeding was an accurate sign of visceral injury. However, in our series it only substantiated a diagnosis previously made on examination of the abdomen. Other rectal or pelvic findings were not of significance.

An elevation in the pulse rate and respiration, and a depression of blood pressure were noted more often in the operative group. Clinical shock was present in 28 per cent of the operative group and 3 per cent of those treated expectantly. In the latter cases the associated injuries easily accounted for the syndrome. The temperature on admission showed no statistical difference between groups.

Exploratory paracentesis was recorded in fewer than 10 per cent of the cases, but over 50 per cent of those recorded were of positive diagnostic value. However, no patient in whom the tap was positive would have been treated conservatively without this supplementary aid nor was the treatment hastened by the positive finding.

Laboratory Findings. Hemoglobin, white blood count and urinalysis were of little help in diagnosis. A leukocyte count over 10,000 per cu. mm. was noted in 34 per cent of those undergoing celiotomy and in 12 per cent of those who were not operated on. In no instance was it of help in deciding therapy. Gross or microscopic blood in the urine was noted with equal frequency in the operative and non-operative groups. Other urinary findings and the level of hemoglobin were not statistically significant.

The value of roentgenograms in the diagnosis of the need for exploration was disappointing. No patient with bowel perforation exhibited roentgenographic evidence of free intraperitoneal air or fluid. Evidence of ileus was divided equally between the two groups of patients. The main value of roentgenograms lay in the localization of bullets and in demonstration of bony and thoracic pathologic conditions.

Associated Injuries. These are summarized in Table VII. Multiple injury was frequent. Forty per cent of the patients in the operative group had associated injuries and 17 per cent had multiple injuries. Five of the deaths are attributable to the extra-abdominal injuries.

Treatment. Primary consideration was given to the management of shock and the restoration of normal respiratory function. Correction of blood volume deficits was always attempted prior to exploration, using both clinical findings and I^{131} blood volume determinations as guides. Splenic lacerations were treated by splenectomy. In liver injuries débridement, hemostatic sutures and drainage were employed in most instances. Lacerations of the stomach and small bowel were sutured after débridement. In multiple closely placed small bowel lacerations resection and closed aseptic anastomosis were performed. Wounds of the colon were treated by suture or by resection and closed aseptic anastomosis without colostomy.

Two patients died before complete assessment of the need for operative therapy could be made. (Table VIII.)

D. R. was a twenty-eight year old white man whose car struck a tree. He was admitted with

dyspnea and abdominal and chest pains. There was diffuse abdominal tenderness but peristaltic sounds were normal. There was a flail in the upper left side of the chest and fracture of the left femur. Despite tracheostomy and assisted ventilation the patient became comatose with bilateral Babinski signs; he died shortly thereafter. At autopsy there were contusions of the heart and aorta with multiple rib fractures and hemothorax secondary to pulmonary laceration. No intra-abdominal injury was found.

J. M., a sixty-three year old white man, was struck by a car. He was moribund on admission. At autopsy a ruptured spleen with hemoperitoneum was found.

One hundred twenty-five patients were not treated surgically for their abdominal injuries. Minor débridement of wounds was carried out as necessary. There was one death in this group.

R. N. was an eighteen year old Puerto Rican boy whose car struck a telephone pole at 90 M.P.H. He was thrown 75 feet from the car and was decerebrate on admission. There were abdominal and chest abrasions. The abdomen was soft and bowel sounds were normal. Operative repair of the partially amputated right arm with brachial artery and radial nerve repair and open reduction of the humerus were performed. The patient died twenty-two hours after admission. Autopsy revealed a subdural hematoma, cerebral contusion and pulmonary hematoma, but no intra-abdominal injury.

Twenty patients had minor febrile episodes and two had superficial infections of their stab wounds, but no morbidity could be attributed to lack of exploration.

Fifty-three patients underwent celiotomy. Of these, forty patients had intra-abdominal injuries which justified operation. (Table IX.) Hemoperitoneum was found in twenty-seven patients; eighteen had over 1,000 cc. of blood. Bile leakage was noted in two patients, gastric leakage in two patients and fecal spill in four patients. Eight patients in this group died.

G. A., a sixty-nine year old white man, was struck by an auto. He was admitted with signs of diffuse peritoneal irritation and moderate shock. In the operating room three hours later, massive hemoperitoneum from a liver laceration was found. The laceration was sutured over a Gelfoam® pack and drained. A fracture of the tibia was treated by closed reduction. The patient did well but died suddenly on the fifth postoperative day. An autopsy failed to reveal the cause of death.

TABLE IX
STRUCTURES INJURED*

Structure	No.
Abdominal wall, non-penetrating	20
Through peritoneum, no intra-abdominal injury	13
Stomach	8
Jejunum	4
Ileum	6
Colon	5
Spleen	16
Liver	9
Gallbladder	2
Pancreas	2
Kidney	2
Bladder	3
Portal vein	1
Gastrohepatic omentum	2
Gastrocolic omentum	5
Greater omentum	4
Diaphragm	3
Retroperitoneum	4

* As noted at operation or autopsy.

S. J., a thirty-two year old Negro man, was admitted with multiple stab wounds of the abdomen. He reached the operating room in thirty minutes. On celiotomy 1,500 cc. of blood mixed with gastric contents was noted. Lacerations of the stomach, gastrocolic and gastrohepatic omentum were sutured. Postoperatively urinary extravasation developed from a rupture of the urethra which occurred during a traumatic catheterization. He died while suprapubic cystostomy was being performed. An autopsy disclosed an unrecognized stab wound of the pancreas and a perirenal hematoma. The site of the urethral rupture was not identified.

J. B., a twenty-seven year old white man, was admitted with two thoracoabdominal bullet wounds. The patient had been held in another hospital for twenty hours without therapy. He arrived in profound shock with hemiplegia, and reached the operating room four hours later. A hole was found in the transverse colon, gastrocolic omentum and liver, with fecal leakage and purulent peritonitis. The lacerations were repaired and a closed thoracotomy drainage established for the left hemopneumothorax. The patient died twenty-two hours after admission. There were no other findings at autopsy.

A. C., a thirty year old Negro man, was admitted with multiple stab wounds. He had signs of diffuse peritoneal irritation; bowel sounds were absent. Blood was found on paracentesis. At celiotomy two hours later a 2,000 cc. hemoperitoneum with lacerations of the stomach, liver, spleen, diaphragm and transverse mesocolon were present. Splenec-

tomy and suture of the liver and gastric lacerations were carried out. A gastroenteric fistula and hemorrhagic pancreatitis developed on the fourth postoperative day. The patient died on the seventh postoperative day. At autopsy there were no additional findings.

R. B., a twenty-two year old Negro man, entered the hospital with two thoracoabdominal bullet wounds. On admission there were signs of diffuse peritoneal irritation. Marked respiratory difficulty from the left hemopneumothorax necessitated resuscitation before surgical therapy of the abdominal condition could be attempted. At exploration lacerations of the stomach, right kidney, diaphragm and spleen were found. The spleen was bleeding freely into the left hemithorax. The bullet had lodged in the lumbar spine with partial paraplegia. The stomach and diaphragm were sutured following splenectomy. Postoperatively, a subphrenic abscess and a leak at an unrecognized esophageal perforation developed. Two subsequent explorations failed to close this perforation adequately, and the patient died on the seventeenth postoperative day. At autopsy a large left subphrenic abscess and acute pancreatitis were found.

N. F., a sixty-five year old white man, was struck by an auto and sustained multiple open comminuted fractures of the right lower extremity and right pelvis. Moderate shock was present on admission, with lower abdominal tenderness and diminished bowel sounds. A cystogram showed rupture of the bladder. In the operating room four hours later, a rupture of the posterior urethra close to the neck of the bladder was found. A suprapubic cystostomy was performed. The peritoneum was not opened. Severe bronchopneumonia and hemorrhagic cystitis developed and the patient died on the twelfth postoperative day from sepsis. There were no additional findings at autopsy.

F. S., a seventy-one year old white man, had a history of a fall three days before admission. He had signs of diffuse peritoneal inflammation. Three hours later in the operating room a hemoperitoneum from a subcapsular rupture of the spleen was found. Following splenectomy, his convalescence was uneventful until the fourth postoperative day when he died from a cerebrovascular accident.

S. A., a twenty-seven year old white man, had been pinned under a stone wall for ten minutes. He was admitted to the Thoracic Service with marked respiratory distress and paradoxical motion of the chest wall. Bilateral clavicular and rib fractures were obvious. The abdomen was soft, with diffuse tenderness and subcutaneous emphysema. He was seen by the Trauma Service twelve hours after admission; at that time abdominal distention, diffuse tenderness and rigidity and lower abdominal rebound tenderness were present. Bowel sounds were absent. Paracentesis yielded free blood. Other emergency operations delayed exploration for four hours. At exploration a 2,000 cc. hemoperitoneum was found with a complete transected spleen. During splenectomy cardiac arrest occurred. Resuscitation was ineffective. There were no additional findings at autopsy.

In the remaining thirteen cases, exploration revealed no intraperitoneal injury. In two cases there were minimal signs of peritoneal irritation but the omentum protruded through abdominal knife wounds. At celiotomy there was no other intraperitoneal injury. In another recent case, not included in the present study, the patient was seriously intoxicated and semicomatose on admission. The wound was carefully débrided, the omentum ligated and excised and the remainder tucked into the abdominal cavity. He eventually awoke and had an uneventful recovery.

In one additional case herniation of intra-abdominal contents was the sole indication for exploration.

T. S., a forty-five year old Negro man, had a 1 inch stab wound in the right lower quadrant of the abdomen. Examination of the abdomen was within normal limits and the patient was kept under observation. Fifteen hours later a loop of bowel herniated into the abdominal wall and the patient exhibited signs of early intestinal obstruction. Laparotomy was performed and the prolapsed bowel was reduced. There was no other intra-abdominal injury and the patient had an uneventful recovery.

In some patients the abdominal findings do not make it possible to rule out visceral injury.

K. C., a forty-two year old white woman, was struck by an auto. When she was admitted to the hospital, there was abdominal distention with diffuse direct and rebound tenderness and regional spasm. Bowel sounds were absent. Roentgenograms showed a pattern of ileus and multiple pelvic fractures. At exploration there was massive retroperitoneal hematoma but no intraperitoneal injury. The patient had an uneventful recovery.

Since reasonable doubt of visceral injury existed celiotomy was indicated under the

criteria of this study. This represents an unavoidable exploration in which the findings were negative. In the remaining nine cases laparotomy would not have been performed if the indications for celiotomy had been observed more closely.

COMMENTS

Few reports in the literature have been devoted to the diagnostic considerations of abdominal trauma. While it is wiser to perform celiotomy needlessly than to miss the opportunity to repair a remediable defect [7], routine exploration carries a definite mortality and morbidity. The Second Auxiliary Surgical Group performed 333 (10.6 per cent) explorations on patients without visceral injury; there were twenty-four (7.2 per cent) deaths [8]. Rob [9] reports that in 560 laparotomies, sixty-six patients had no visceral injury; nineteen (29 per cent) of these died. Unnecessary operation was considered the major cause of death. Rob believed that careful preoperative examination and diagnostic evaluation were essential even on the battlefield. The operative policy of the Second Auxiliary Surgical Group in World War II as stated by Jarvis [10] was that celiotomy was indicated, with rare exception, for any wound involving the *contents* of the peritoneal cavity. Abdominal injury without intraperitoneal disease does not require exploration, and avoidance of such exploration is desirable. Our experience and that of others [9–13] suggest that such a diagnosis can be established with relative ease and with considerable certainty. With reasonable doubt of visceral injury, few would advise prolonged non-operative management.

Basic questions in the management of abdominal injuries therefore are: (1) What are the diagnostic criteria of visceral injury? (2) Are they reliable? (3) What may be considered reasonable doubt? (4) How long can we wait to resolve these doubts without detriment to the patient? In discussing the diagnosis of intraperitoneal injury Jarvis [10] observed that the usual signs of peritoneal irritation, in the main, were reliable in evaluating the need for exploration. In his review of 128 patients there were no cases of free peritoneal bowel perforation in which peristaltic sounds were audible. In Rob's study [9], peristaltic sounds were absent in eighty-three of eighty-nine patients with visceral injuries. The absence of peristaltic sounds is an absolute indication for exploration, and presence of them is a reliable guide towards conservative management [6,9–12,14,15]. I think this study has shown the reliability of abdominal signs in the diagnosis of abdominal injuries. In the patient in severe shock or with oversedation, signs may be mimimized. However, as these states are corrected, the abdominal signs return [7,10]. The equivocal cases are always difficult. The temptation is to "have a peek," but careful continual observation by the same surgical team in this study has revealed the subtle changes which demand or reject celiotomy [7,9,11,12]. Most of our quandaries were resolved within eighteen to twenty-four hours. In only two patients did splenic injuries become evident more than twenty-four hours after admission. In those operated on 70 per cent reached the operating room in less than four hours and an additional 20 per cent in from four to eight hours. Delay in these cases was not due to a failure of prompt diagnosis. Rarely did we need to worry about the patients in the non-operative group after the first twenty-four hours. In patients who have persistent evidence of peritoneal irritation and continued blood loss or shock [6], which are not attributable to other injuries, reasonable doubt of visceral damage exists, and celiotomy should be performed.

No mortality or morbidity could be attributed to our observant and expectant treatment. The application of trained surgical judgment rather than dogma is the more rational and intelligent approach to the managment of abdominal injury. I am in agreement with Jarvis [10], "With thorough diagnostic consideration negative exploration should become less frequently necessary as the experience of any given surgeon increases with this type of injury."

SUMMARY

One hundred eighty cases of abdominal trauma are presented with a statistical review of signs, symptoms, treatment and results.

The usual signs of peritoneal irritation, especially auscultation of peristaltic sounds, were valuable and reliable guides in determining the need for exploration.

Hematemesis, proctorrhagia or positive abdominal paracentesis were secondary confirming indications for celiotomy.

Vital signs and laboratory studies including roentgenograms were of little value in deciding the need for surgery.

No mortality or morbidity could be attributed to our observant and expectant treatment.

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Perforations of the Distal Large Intestine Produced by Intraluminal Traumas

WESLEY FURSTE, M.D. AND HARVEY KNOERNSCHILD, M.D., *Columbus, Ohio*

From the Department of Surgery of White Cross Hospital and of the Ohio State University College of Medicine, Columbus, Ohio.

THE healthy or diseased distal large intestine may be ruptured by a solid, liquid or gas inserted into the rectum for any reason. This may occur whether the patient is conscious or unconscious. An injury produced by the insertion of a solid object or by the injection of a liquid or gas through the anal canal may not be immediately diagnosed unless it causes a break in the continuity of the skin. Failure to recognize and treat this type of injury will frequently result in the patient's death.

The thirteen patients described in this paper have been observed during a period of thirteen years in eight hospitals in two cities. One of us (W. F.) was asked to treat one of the patients who had a perforation and he assisted in the treatment of two others. The other ten patients were treated by our associates. None of these cases has been reported previously in the literature.

Thirteen cases do not permit an extensive study, but their evaluation suggests certain significant aspects of such perforations. The collection of data from questionnaires which have been sent to numerous centers, or a review of previously published cases, does not always provide all the information desired. In view of the fact that one of these methods has been the basis of several reports on this subject [*7,14,22,25,41*], we believed that a detailed study of our patients would be of value.

Incidence. Because of the unusual nature of these perforations and the reluctance of physicians to discuss such cases, it is difficult to determine the frequency of this injury. Only one injury in this series of thirteen cases was self-induced (Case 1), and only one was produced by a layman (Case 3). The remaining eleven cases occurred in hospitals at the time of enemas or during sigmoidoscopic examinations with or without biopsy. At the Ohio State University College of Medicine 9,195 sigmoidoscopic examinations were performed from October 1, 1957, to September 8, 1959. In only one instance did perforation occur during the examination. In a series of 350,000 protoscopic examinations, Jackman [*17*] reported four instances in which severe injury to the bowel occurred.

Some of the large series of reported cases in which perforations occurred are listed in Table 1. Most of these reports, however, are based on review of the literature or on data obtained from questionnaires, and they emphasize the fact that a surgeon observes few injuries of this type during his period of practice.

Etiology. Perforation of the intraluminal distal large intestine may be caused by any one of a number of things; it may be the result of the insertion of an air hose outlet into the anorectal canal [*11,22,34*]; it may be produced by the abnormal practice of a neurotic person who inserts a long thin object through his anus (Case 1); it may occur as a result of accidental impalement when a person jumps off a truck or slides off a haystack [*30*]. These injuries are common in agricultural regions where offending instruments are frequently the handles of pitchforks and brooms [*21*]. Corn stalks, dry weeds standing upright and stubs of wood have also penetrated the anal orifice [*23*].

Two thousand years ago the Chinese used impalement as a method for the execution of criminals. As civilization progressed, impalement was reserved for important persons when it was undesirable to leave a visible body scar. In 1327, King Edward II of England was mur-

TABLE 1

MORTALITY RATES OF PATIENTS WITH PERFORATION OF THE DISTAL LARGE INTESTINE PRODUCED BY INTRALUMINAL TRAUMAS

Auti. and Year	Type of Trauma	No. of Cases	Mortality Rate (%)
Pearse, 1941 [25]	Instrumental perforations	72	56
Lapp, 1945 [22]	Pneumatic ruptures	68	68
Andresen, 1947 [1]	Proctoscopy	94	48
Zheutlin, Lasser and Rigler, 1952 [41]	Barium enema	53	51
Klein and Scarborough, 1953 [19]	All types	33	12
Grillo and Nardi, 1958 [13]	Cleansing or barium enema into colonic stoma	17	29
Grodsky, 1959 [14]	Barium enema of colon and rectum	18	50
Furste and Knoernschild, 1960 (present series)	All types	13	31

dered by deliberate penetration of the rectum [10,14,25].

Diagnostic and therapeutic procedures, such as barium enemas and sigmoidoscopic examinations, may be immediate causes of such perforations [1,13,14] (Cases 5 and 6). Perforation may occur during the removal of intestinal lesions through the sigmoidoscope or when cleansing enemas are given, particularly when a hard enema tip is used [13,19,28] (Cases 3 and 9).

There may be certain conditions which cause a predisposition to intraluminal perforation of the bowel. Any chronic disease may cause weakness of the tissues, and the patient's resistance to any intraluminal force on the bowel wall may be reduced. A carcinoma of the sigmoid colon, diverticulitis of the large intestine, or Hirschsprung's disease may result in a weakened large bowel which can be easily ruptured [14] (Case 2). Previous abdominal or pelvic operations may have altered the position or length of the colon causing acute angulations which are prone to injury (Case 10).

Clinical Manifestations. The symptoms and signs vary considerably with different patients, with the size of the intestinal perforation, and with its intraperitoneal or extraperitoneal position. When there is an intraperitoneal perforation, the intestine has been opened into the peritoneal cavity so that the intestinal contents may leak out and produce peritonitis. When the perforation is extraperitoneal, the intestine has been opened either into its mesentery or into the subperitoneal perirectal area so that peritonitis does not develop.

The definite history of one of the immediate causes of such injury is most important in making the diagnosis. In our Case 1, for example, delay in establishing the diagnosis and in operating occurred because of an inadequate history. Not until an emergency exploratory laparotomy was scheduled did the patient tell the examiner how he had injured himself.

At the time of an intraperitoneal perforation, the patient may complain that "something gave way" (Case 1). There may be a period of an hour or two in which the patient is relatively asymptomatic. This is the period when the clinician should be aware of the catastrophe which has occurred and start intensive therapy. Peritonitis will develop because of gross fecal contamination if treatment of the injury is delayed. Then the patient will begin to complain of abdominal discomfort followed by pain which may become intense rapidly. These symptoms may be associated with vomiting. In the elderly patient (Case 12) these symptoms may be less pronounced than in younger patients so that the physician may not realize that a perforation has occurred.

In the event that the perforation is located intraperitoneally, the onset of the signs is parallel to that of the symptoms. Within several hours after the accident, the pulse rate rises to approximately 120, the temperature may be somewhat elevated, and the abdomen becomes distended, rigid and tender; there is an absence of peristaltic sounds. If the perforation is produced by insufflation with compressed air, the patient may have an extremely distended abdomen [34]. A diagnosis can

usually be made before shock occurs. Occasionally, as in Case 11, bleeding may be associated with the perforation so that shock can develop from blood loss.

The symptoms and signs may be quite minimal in the patient who has an extraperitoneal perforation. In Case 5, for example, perforation of the rectum occurred at the time of barium enema. The patient had so few complaints, and exhibited such minimal signs that a non-operative course was successfully followed.

Digital examination of the rectal canal and inspection of the distal large intestine through the sigmoidoscope may be quite helpful in establishing a diagnosis in a questionable case; it may also help to differentiate between an intraperitoneal and extraperitoneal perforation. Such examinations may localize the site of trauma so that a more specific operative approach to an intraperitoneal perforation can be planned. If an intraperitoneal perforation occurs during sigmoidoscopic examination, the sigmoidoscope may be left in place and taped to the patient's buttocks. The perforation can then be found without delay by locating the tip of the sigmoidoscope at laparotomy [*10*].

The roentgenogram and the hemogram may also be of help. If there is a relatively large perforation, a layer of free gas may be seen under the diaphragm in a film taken while the patient is erect (Fig. 6B) or underneath the lateral portion of the peritoneum in a lateral roentgenogram taken while the patient lies down. In the event of a perforation at the time of an examination with a barium enema, the roentgenologist should notice the extraluminal position of the barium. (Fig. 1.) A barium enema should not be given to prove that a perforation is present, for it will result in further peritoneal contamination with fecal matter and in further delay in a situation in which time is an important factor. If considerable bleeding is associated with the perforation, the hemoglobin and hematocrit values fall. As the peritonitis becomes more severe, leukocytosis occurs and the percentage of immature neutrophils increases.

Treatment. No statistical conclusions can be made concerning treatment from this series of thirteen cases. Certain principles seem to be indicated, and further evidence to support them is found in other similar studies [*1,13,14,19,41*].

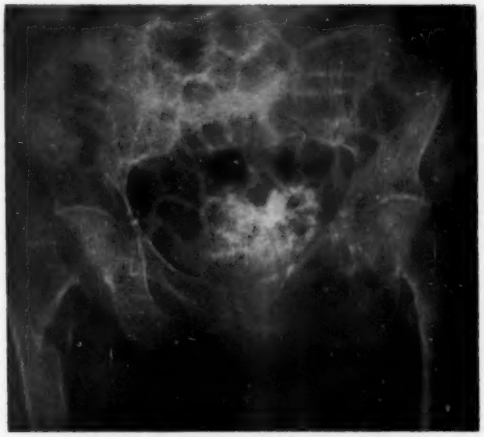


FIG. 1. Case 5. Pelvic extravasation of barium through an extraperitoneal rectal perforation at the time of a barium enema. This barium was present about six months after the rectal perforation when the patient entered the hospital for treatment of an intertrochanteric fracture of the right femur.

Immediate diagnosis of the injury is most important because the severity of the peritonitis associated with a perforation seems to be roughly proportionate to the duration of the perforation before operative closure is carried out [*1,14,19*]. In 1936, Crohn and Rosenak [*9*] stated that when treatment is delayed for seven hours or more there is a 100 per cent mortality rate in patients with perforations of the sigmoid colon. In 1941, Pearse [*25*] pointed out that a delay of seven hours or more in operative closure of an instrumental perforation of the rectosigmoid colon is always fatal. However, the physician should not consider the situation hopeless even though the perforation has occurred some hours before treatment. In the twelve patients with intraperitoneal perforations described in this paper, the intervals between the occurrence of the perforation and surgical intervention in eight patients treated successfully was as follows: one-half hour, three, five, six and one-half, seven, seven, twelve and thirteen hours; the length of the intervals in the four who did not survive was three, five, five and eight and one-half hours. (Fig. 2.)

Immediate laparotomy to carry out the procedure indicated is as essential as immediate diagnosis [*1,13,14,19,36*]. The choice of treatment may be difficult: primary closure may be performed or some type of colostomy is elected.

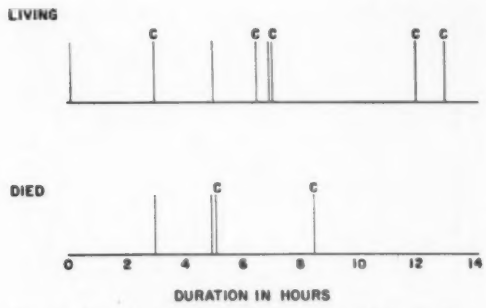


FIG. 2. The relationship of the duration of the perforation before operation and of the success of treatment for the intraperitoneal perforations. Each vertical line represents one patient. A colostomy type of procedure (C) was used in four of five patients who survived and who were treated six and one half hours (or more) after perforation occurred. The patients, in whom therapy was instituted twelve and thirteen hours after the injury, recovered.

The latter may be (1) exteriorization only, (2) drainage of the area of perforation and a proximal colostomy, (3) closure of the perforation and a proximal colostomy, or (4) resection of a perforated colon proximal to a colonic stoma and a new colostomy. In this series of twelve patients with intraperitoneal perforations, primary closure of the intestine was the only surgical procedure performed in five instances; two of the patients died. In seven patients, the procedure of choice was some type of colostomy; two patients died. Of the eight patients with intraperitoneal perforations who were successfully treated, five had some type of colostomy. Of the four patients who died, two had a colostomy. Of the five living patients whose perforations had occurred six and one-half hours or longer before treatment, four were treated by colostomy. (Fig. 2.)

Primary closure may be justified when the lesion is detected within several hours of occurrence, the perforation is small, the injured area has a good blood supply, the injured bowel appears to be viable, the associated inflammation is minimal and localized, and when a good surgical closure of the perforation can be accomplished. (Table II.) When these favorable circumstances are not present, some type of colostomy should be undertaken.

If the mortality rates are to be reduced, supportive measures must be meticulously performed. Fluid and electrolyte needs as well as blood replacement requirements are to be met. Decompression of the proximal gastrointestinal tract by a Levin tube or gastrostomy [*42*] should be instituted until the associated ileus is overcome. Oxygen is indicated for cyanosis. Antibiotics or chemotherapeutic agents should be given in adequate amounts, empirically at first and then as indicated by cultures and bacterial sensitivity tests [*7,27*]. A prophylactic dose of tetanus antitoxin or a booster dose of tetanus toxoid should be administered [*5,28,39*].

TABLE II
COMPARISON OF INDICATIONS FOR PRIMARY CLOSURE AND LOCAL OR PROXIMAL COLOSTOMY

Primary Closure	Local or Proximal Colostomy
Short duration	Long duration
Small perforation	Large perforation
Good blood supply	Poor blood supply
Viable intestine	Non-viable intestine
Minimal, localized inflammation	Spreading peritonitis
Good surgical closure	Poor surgical closure

For the infrequent patient with extraperitoneal perforation of the lower rectum, nonoperative therapy may suffice (Case *5*). If there is any evidence of a spreading perirectal or presacral cellulitis, proximal colostomy should be performed [*19,23*], and posterior drainage of the perirectal and presacral areas should be considered [*23*].

Mortality Rate. As may be seen in Table I, the mortality rate in these types of injuries is not low. In addition to the reports referred to in this table, there are a number of publications in which one or several cases have been reported and for which the mortality rate has been from 0 to 100 per cent [*2,3,6,8,11,12,15,16,18,20,21,23,24,26,28,35,37,38,40*].

A number of factors contribute to the guarded prognosis in these cases. (Table III.)

TABLE III
FACTORS RESPONSIBLE FOR HIGH MORTALITY RATE IN PATIENTS WITH INTRALUMINAL PERFORATIONS OF THE DISTAL LARGE INTESTINE

Poor condition of patient
Unsatisfactory bowel preparation
Gross peritoneal contamination
Delay in treatment
Difficulty in mobilization
Difficulty in closure

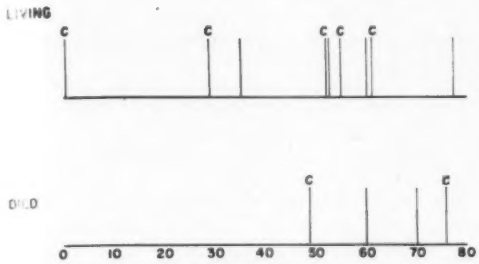


FIG. 3. Age as a factor for the mortality rate among patients with extraperitoneal perforations or intraperitoneal perforations. Each vertical line represents one case. (C) indicates a colostomy type of procedure. The patients who died were forty-nine years of age or older.

Some of the patients are in relatively poor condition prior to the time of the intraluminal perforation. Of the four patients in this series who died, three had associated disease and the fourth was seventy years old. In this series those who survived were from one week to seventy-seven years of age and those who died were from forty-nine to seventy-six years old. (Fig. 3.) In most of these patients the preparation of the bowel is not acceptable for colonic surgery as the cleansing enemas, when administered, do not completely remove the feces, and an antibiotic or chemotherapeutic bowel preparation has not been given. The explosive type of injury which occurs with such perforations allows free egress of feces from the colon into the peritoneal cavity so that there is gross peritoneal contamination. In many instances, the perforation is not recognized immediately, and the therapy indicated is not started until a generalized peritonitis has developed. If the site of the injury is the distal sigmoid colon just above the rectum, as it usually is, mobilization of the traumatized bowel and closure of the perforation may be difficult. The problems associated with adequate intestinal closure are complicated when the local blood supply has been impaired or inflammation prevents the necessary tissue dissection.

CASE REPORTS

The details of the thirteen cases are summarized in Table IV. Two cases were particularly interesting.

One patient, who was neurotic, had been inserting a broom handle into his anorectal canal for a number of years. He presented a diagnostic problem, for he did not tell the examiner how he had injured himself until an operation had been decided upon. An interesting operative finding was the presence of old adhesions in the area of the rectosigmoid colon

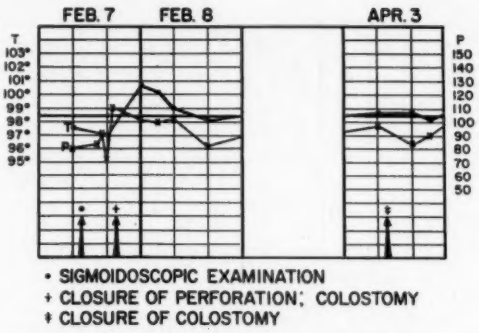


FIG. 4A. Outline of the hospital course of a fifty-five year old white woman (Case 6) who had her sigmoid colon perforated by a sigmoidoscope followed by a barium enema. The perforation was closed; the peritoneal cavity was repeatedly irrigated to remove barium and feces, and transverse colostomy was performed.

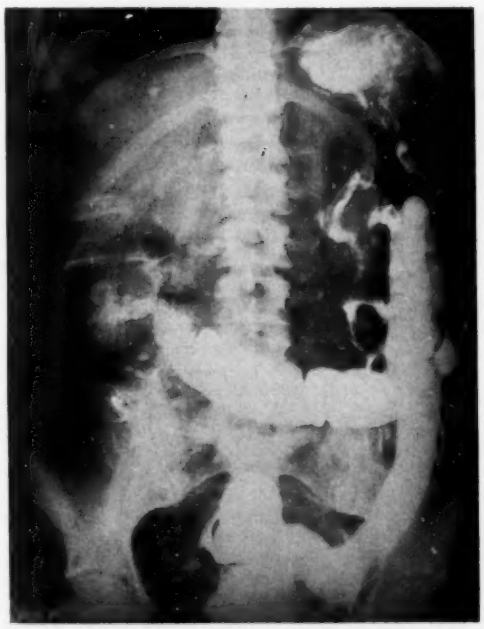


FIG. 4B. Case 6. Roentgenogram taken during a barium enema which was given about two months after the accident and before the colsure of the colonic stoma. Note the residual barium outside the colon and in the splenic area.

TABLE IV

SUMMARY OF THIRTEEN CASES OF DISTAL LARGE INTESTINE PERFORATIONS PRODUCED BY INTRALUMINAL TRAUMAS

Case No.	Age (yr.), Race and Sex	Cause of Perforation	Site of Perforation	Previous History	Time Between Perforation and Time of Operation (hr.)	Treatment	Result
1	35,W,M	Insertion of broom handle through anorectal canal by patient	Distal sigmoid colon	Similar manipulations without serious result during the preceding 20 years	7	Primary closure	Lived
2	1 wk.,N,M	Cleansing enema	Sigmoid colon	Hirschsprung's disease	13	Exteriorization of perforation, resection of aganglionic intestinal segment and closure of sigmoid colon stoma	Lived
3	29,W,M	Cleansing enema by wife	Proximal sigmoid colon	Constipation	7	Closure of perforation and transverse colostomy, drainage of abscesses, closure of colonic stoma and small bowel fistulas	Lived
4	60,W,F	Barium enema	Distal sigmoid colon	Proctitis	3	Closure of perforation	Died
5	77,W,F	Barium enema	Rectum	Ulcerative colitis, polyps of colon, traumatic ulcer of left thigh		Supportive measures, no operation	Lived
6*	55,W,F	Sigmoidoscopic examination	Distal sigmoid colon	Radiation for adenocarcinoma of uterus	6½	Primary closure and proximal colostomy, closure of colonic stoma	Lived
7	70,W,M	Sigmoidoscopic examination	Distal sigmoid colon	Admission for evaluation	5	Primary closure, drainage	Died
8	53,W,F	Sigmoidoscopic examination	Distal sigmoid colon	Melena, hemorrhoids	12	Descending colostomy and drainage; closure of colonic stoma	Lived
9	53,N,M	Biopsy excision of polyp of sigmoid colon through sigmoidoscope	Distal sigmoid colon	Admission for evaluation, inguinal and umbilical hernias	5	Primary closure	Lived
10	60,N,M	Biopsy of distal large intestine through proctoscope	Distal large intestine	Anterior resection of rectosigmoid colon for carcinoma several years previously	½	Primary closure	Lived
11	49,W,M	Biopsy of sigmoid colon through sigmoidoscope	Distal sigmoid colon	Cirrhosis of liver with portal hypertension and ascites, inactive duodenal ulcer	8½	Transverse colostomy	Died
12	76,W,F	Cleansing enema given through colonic stoma	Descending colon proximal to colonic stoma	Combined abdominoperineal resection for carcinoma of rectum about 10 years previously, operation for cataract	5	Resection of perforated colon and new colostomy, revision of retracted colonic stoma	Died
13	61,W,M	Barium enema given through colonic stoma	Descending colon proximal to colonic stoma	Combined abdominoperineal resection for carcinoma of rectum 2½ years previously	3	Resection of perforated colon and new colostomy	Lived

NOTE: In Case 5 there was an extraperitoneal perforation which was located in the rectum inferior to the pelvic peritoneum. The other twelve perforations were intraperitoneal.

* Figure 4.

which were presumably the result of previous, self-produced, intraluminal injuries.

CASE 1. This thirty-five year old white man complained of severe abdominal pain of several hours' duration. He stated that he had inserted a broom handle into his anal canal and up into his rectum for a distance of approximately one foot at about 4:30 P.M. on September 12, 1946. While pushing on the broom handle, he suddenly felt "something give way" and immediately experienced sharp abdominal pain. The pain gradually became

more severe, and was present at the time of emergency admission to the hospital which was approximately five and one-half hours after the accident happened. He vomited at least ten times. The patient said that for about twenty years he had periodically inserted objects into his anal canal for the pleasure it afforded him.

He appeared to be well developed, well nourished, acutely ill, slightly cyanotic and pale. His temperature was 102.2°F., the pulse rate was 102, and the respiratory rate was 26. The blood pressure was 128/68 mm. Hg. The skin of the extremities was cold and pale. Examination of the abdomen showed board-like rigidity, generalized tenderness, no liver dullness, and no peristaltic sounds. The digital anorectal examination was within normal limits.

The hemoglobin was 14 gm. per cent and the total leukocyte count was 12,400 per cu. mm. The urinalysis was essentially normal. Erect and lateral decubitus roentgenograms of the abdomen indicated no free gas.

Exploratory laparotomy was performed through an incision in the left lower quadrant of the abdomen approximately seven hours after injury. A considerable amount of thin, malodorous pus was found in the pelvic cavity. The sigmoid colon was adherent by old adhesions to the promontory of the sacrum, and a perforation 1.5 cm. in diameter was found on the anterior wall of the sigmoid colon just above the junction of the rectum and the sigmoid colon. (Fig. 5.) The perforation was closed with several layers of interrupted silk sutures. Postoperative supportive measures included the administration of streptomycin. The temperature and pulse rate were normal to slightly elevated until the seventh postoperative day when they became moderately elevated due to an infection in the superficial fascia. After the wound was drained, the course was one of steady improvement. The patient was discharged one month after admission.

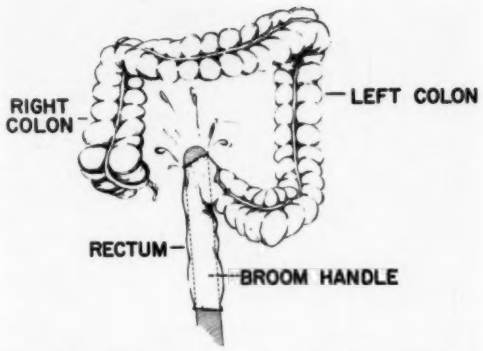


FIG. 5. Case 1. Perforation of the distal sigmoid colon by a broom handle which had been self-inserted through the anorectal canal.

In the following case, the difficult diagnostic problem of a colonic perforation in an infant who was two days old is discussed. An alert resident staff noticed that the patient was becoming distended, and ordered the roentgenogram which made possible an immediate diagnosis of an intestinal perforation.

CASE II. This two day old Negro boy was transferred from a general hospital to a pediatric hospital because of vomiting since the day of birth.

On February 28, 1951, the day after birth, the patient was started on feedings. He took them poorly, and regurgitated after the feedings. He had one meconium stool. On March 1, 1951, the infant vomited green fluid persistently.

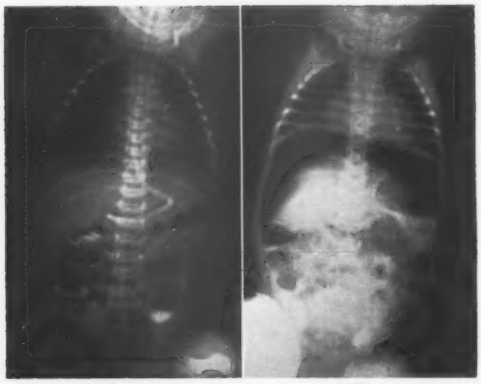
When the infant was admitted to the pediatric hospital, he had a distended abdomen. The temperature was 95.8°F., the pulse rate was 128, and the respiratory rate was 34. The abdomen was tense, and bowel sounds were audible. On digital rectal examination, a narrowed portion, suggestive of a constricting band, was felt in the rectum approximately 2 to 3 cm. superior to the anus. The remainder of the physical examination was noncontributory except for a hypospadias of the penis.

The hemoglobin was 23 mg. per cent. There were 10,000 leukocytes per cu. mm. with 6 per cent band neutrophils, 80 per cent segmented neutrophils, 11 per cent lymphocytes and 3 per cent monocytes. Urinalysis showed no abnormal findings.

A barium enema was performed because of the distention. This indicated a distended colon and what appeared to be a narrowed area at the junction of the rectosigmoid colon. It was thought that this patient probably had Hirschsprung's disease, and a regimen to correct this condition was instituted immediately. Gastric suction and rectal irrigations were begun. The patient defecated numerous times and became less distended.

On March 6, 1951, about eight hours after a routine rectal irrigation, the abdomen was greatly distended. A roentgenogram showed a large amount of free gas under the diaphragm. (Fig. 6B.)

Thirteen hours after the cleansing enema, emergency laparotomy was performed through an incision in the right rectus muscle. Fecal material was found in the peritoneal cavity. Inspection of the descending colon and the sigmoid colon indicated a small perforation in the sigmoid colon with fibrous exudate. A localized, purulent material surrounded this perforation. The large intestine was dilated and thick-walled. The descending colon was tightly packed with inspissated masses of barium. The perforation was exteriorized through



6A 6B

FIG. 6. Case 2. A, roentgenogram of the abdomen taken March 3, 1951. This infant had Hirschsprung's disease. B, roentgenogram taken March 6, 1951, eight hours after a cleansing enema and prior to surgical intervention. In (B) note the large amount of free gas in the peritoneal cavity underneath the diaphragm.

an incision in the muscle of the left lower quadrant. The right rectus incision was closed.

The patient's postoperative progress was poor for a considerable length of time. With the indicated diet and antibiotics, his condition gradually improved. At the time of discharge on May 31, 1951, his weight was 8 pounds 6 ounces. His birth weight had been 6 pounds and 4 ounces.

In December 1951 the patient was readmitted to the hospital for surgical treatment of Hirschsprung's disease and closure of the sigmoid colon stoma. He had spontaneous bowel movements per rectum after this treatment.

SUMMARY

Thirteen cases of perforation of the distal large intestine produced by intraluminal injuries are presented. One of these perforations was self-produced by insertion of a broom handle into the anorectal canal; one was the result of a cleansing enema given by the patient's wife; and the remainder occurred at the time of diagnostic or therapeutic procedures.

Although it is difficult to determine the true incidence of such injuries, several surveys indicate that such accidents may be more common than we realize.

In addition to the etiological factors involved in the thirteen cases presented, a review of other possible etiological factors is given.

The clinical manifestations are reviewed. Intraperitoneal perforations usually are more serious than extraperitoneal perforations. Both types of perforations should be diagnosed and supportive measures instituted immediately.

With an intraperitoneal perforation emergency laparotomy is mandatory unless the patient is moribund. If circumstances are quite favorable, primary closure may be the only operative intervention. If the findings are not favorable, some type of colostomy should be performed.

In the event of an extraperitoneal perforation involving the lower part of the rectum, nonoperative therapy may suffice. However, a proximal colostomy may be necessary, and drainage of the perirectal and presacral areas may be indicated.

The mortality rate is not low. In several large series, the rate varied from 12 to 68 per cent with the majority of the figures being closer to the higher rate. The rate was 31 per cent among the thirteen patients discussed herein.

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DISCUSSION OF PAPERS BY DRS. ROOF, MORRIS AND DE BAKEY; ECONOMY, KOUCKY AND NOVACK; PATTON AND JOHNSTON; SHAFTAN; AND FURSTE AND KNOERNSCHILD

WILLIAM L. ESTES, JR. (Bethlehem, Pa.): It is tempting to discuss this splendid symposium on abdominal injuries in detail. However, I shall confine my remarks to underscoring certain striking attributes of non-penetrating abdominal injuries in general. Our series of blunt abdominal trauma consists of 152 patients, of whom twenty-three died (mortality 15 per cent). The chief contributors to this mortality were injuries to the solid viscera, such as liver and spleen, and the high incidence of multiple injuries. Other factors in producing mortality were found to be failure to recognize an abdominal emergency, late recognition of a ruptured viscus, and delay in onset of rupture or hemorrhage or of signs of rupture or perforation.

The delay in symptoms and signs of rupture may be due to shock, intestinal spasm, plugging of laceration by clot, adhesion, or by omentum, delay in actual rupture and concomitant multiple injuries.

Decision for immediate operation should be made within six to eight hours of injury. The greatest aid in determining whether a rupture has occurred and an operation is indicated is the repeated physical examination of the patient by the same surgeon at frequent intervals—changes in signs and symptoms may take place rapidly, particularly after treatment for shock. History, blood counts, urinalysis and especially x-ray examination and abdominal paracentesis are exceedingly valuable aids in diagnosis but the evidence obtained from repeated abdominal examination is by far the most revealing as rapid changes may occur during observation which indicate that an operation is imperative. Decision to operate should be made within five to six hours of the injury. In those cases in which a definite diagnosis of rupture cannot be made in this interval but in which progressive deterioration continues, exploratory laparotomy is justified.

In multiple injuries a concomitant extensive injury to the chest or open fracture of the skull with coma may obscure the signs and symptoms of abdominal visceral rupture. Nevertheless, in fracture of the lower rib cage, even if only one or two ribs are involved, a possible laceration of the liver or spleen must always be suspected.

Occasionally the concomitant lesion may be so obvious that abdominal involvement may be overlooked, and primary care of this injury may fall to the lot of a neurosurgeon or some other specialist. Fortunately the present trend of training in any

surgical specialty is to include two to three years of general surgery. This should provide an adequate background to alert the specialist to the dangers these unsuspected multiple injuries will present.

CHARLES G. JOHNSTON (Detroit, Mich.): This has been an extensive discussion on many types of abdominal injuries. I quite agree with Dr. Roof that a direct approach to injury to the colon is a much better one than an indirect approach; if the injury is extensive enough, it is much better to perform a right transverse colostomy than exteriorization.

What has not been mentioned is perforation of a diverticulum. We have seen patients a week or more after perforation who complain chiefly of distention. On examination we found massive amounts of air under the diaphragm. There may be 1 or 2 inches or more of air space between the diaphragm and liver, and in such instances one can be fairly sure that it is caused by a ruptured diverticulum. In most instances peritonitis is not present in any great degree because of the solid nature of the material and small amount of virile organisms that go out with the gas.

It has been mentioned that diagnostic procedures are not reliable. I think we might say that they are not reliable when the results are negative. On peritoneal tap, the report is often "no fluid in the peritoneal cavity," and the assumption is that there is none. We perform this procedure quite regularly, not in lieu of physical or other examination, but when it is indicated. In relation to the rupture of the spleen, which Dr. Novack has mentioned, this procedure has been of great help in making a definite diagnosis especially when fresh blood is found in the cavity.

Dr. Patton's study has been so well presented that I can add nothing. He has been interested in this problem for a long time; in fact it was he who designed the first effective tube for tamponade of esophageal varices.

According to Dr. Shaftan the idea of exploration of penetrating injuries came during the war. He did not say which war. I suspect it was the Spanish-American War, because I have seen it in textbooks for many years. In the majority of people with penetrating injuries of the abdomen some type of injury to the viscera will also be present. When no injury is present exploration ought to be safe.

Another remarkable feature of Dr. Shaftan's paper was the high mortality rate that they had with simple exploration. One should not expect a high mortality from looking to see whether the abdomen was penetrated. Obviously patients should be followed up, but it seems to me that as a general principle making sure no perforation exists by exploration is good practice. If one assumes that a delay of one or two days will make little difference and waits for specific signs to develop, fewer operations will be performed, for in many instances signs do not develop. However, the mortality of those with a viscus injury will be greater.

JAMES M. WINFIELD New York, N. Y.): Admittedly, traumatic extrahepatic portal obstruction is a rather uncommon complication, but I honestly believe that if more of our patients with severe upper abdominal injury were followed up, we would find that this type of lesion had developed.

In the first case that Dr. Patton mentioned, I do not believe the portal vein was injured, but rather that the inferior vena cava sutures were placed and as the patient's condition became most critical, a firm pack was inserted producing a practically complete immediate occlusion of the portal vein.

I remember discussing this case with Dr. Johnston. We know that patients can survive an immediate obstruction. Unquestionably, it would seem logical that they develop extrahepatic obstruction as a later sequellae. There are other conditions, and Dr. Patton mentioned them, that may present themselves; I am reminded of two cases in which a complicated hepatic ductal system produced a severe gastrointestinal hemorrhage; one patient underwent laparotomy and we were able to correct the situation; the other died. At postmortem examination the cause of death was found to be due to an arteriovenous fistula deep in the substance of the left lobe of the liver. Therefore, it seems apparent that faced with initial emergency problems of this type, we must consider the long range possibilities of lethal complications which may recur and, if not properly evaluated and treated, may well result in failure.

I listened with considerable interest to the discourse about abdominal tap. I cannot see why it should be condemned because it is a perfectly simple procedure, although a great many people do not do it correctly. It should be performed on all four quadrants and repeated. If the results are negative, it means nothing, but if they are positive, it means a great deal. If I interpreted Dr. Shaftan's paper correctly, I totally disagree. I think it is dangerous teaching. It may be all right for an expert individual or a group of individuals with great experience, but I cannot see why you should worry and sit down and watch a patient when there is a question of a penetrating wound of the abdomen. I think that is very dangerous. I personally cannot determine, just as Dr. Johnston said, what has occurred inside the abdomen. I think, as Dr. Estes said, that the same group of surgeons should watch such patients, that such patients should undergo laparotomy. Why Dr. Shaftan had such a high mortality rate in patients undergoing this procedure is beyond my comprehension.

EDWARD NEWELL, JR. (Chattanooga, Tenn.): These papers have had wonderful statistical summaries, and I would like to comment on two specific and interesting personal cases. One was an

eighteen year old prep school boy who had a football injury. He was admitted to the hospital with gross hematuria with a diagnosis of contusion of the left kidney and possible splenic injury. He was treated expectantly and was dismissed after one week to the school infirmary where he was confined for another week, but permitted to go to classes. Twenty days after injury, after he had been dismissed from observation, he had an abdominal hemorrhage from a ruptured spleen. Following emergency splenectomy he made an uneventful recovery. This was interesting to me because I was under the impression that delayed rupture of the spleen usually occurred in five to ten days after the injury; I did not realize that delayed rupture of the spleen may occur as late as three weeks after injury.

The other case was that of a large traumatic rupture of the left diaphragm with diaphragmatic hernia. This is a rare injury from blunt abdominal trauma as has been shown by the statistical analysis in the previous papers. This patient was a twenty-eight year old miner who was injured in the mines near Chattanooga. He was admitted to the hospital with multiple fractures of the pelvis, severe comminuted fracture of the right femur, fracture of the transverse processes of the first, second, third and fourth lumbar vertebrae; and a traumatic rupture of the left diaphragm.

The patient was in respiratory distress and shock, and the resident was preparing to perform a thoracentesis for an acute spontaneous pneumothorax. I suggested we should take a roentgenogram of the chest first. After treatment for shock, this patient had an emergency repair of the hernia through a left thoracoabdominal incision and made a satisfactory recovery.

G. W. SHAFTAN (closing): I knew there would be marked disagreement with some of our beliefs. We have adhered to Dr. Estes' principles and our patients are followed up at frequent intervals by the same surgical team in order to evaluate them and note the changes which will demand or reject celiotomy. Seventy per cent of our patients reached the operating room in four hours, 20 per cent in four to eight hours. In none of these instances was the delay in reaching the operating room due to delay in diagnosis. Two patients reached the operating room after twenty-four hours; both survived.

I should explain our mortality rate in the group with negative findings at laparotomy. In the initial series one of seventeen patients died, and in the later series (which was presented here) there was no mortality. In the group of patients with abdominal injuries, eight died. Two deaths were due to delay in reaching the hospital; one patient had a cerebral vascular accident; one had a postoperative urethral rupture that accounted for the death; two patients died as a complication of multiple injuries, and two died as a result of extra-abdominal injuries. None of the deaths was attributed to a delay in diagnosis.

We have had seventy-seven patients with abdominal trauma since the first of the year. Twenty-two were explored; and nineteen required exploration. There were three deaths in the operated group, all due to secondary complications of multiple trauma. Of the three patients with negative findings on exploration, two had omentum protruding from the wound and one patient had no visceral injury, but the physical findings did not permit accurate diagnosis. There was no morbidity or mortality in the fifty-five patients who were not operated on. I agree that when there is a doubt regarding visceral injuries, exploration is necessary.

Acid Debridement of Burned Rats and Men

NICHOLAS S. GIMBEL, M.D., FREDERICK WEISSMAN, M.D., JOSEPH SCHIRLE, M.D. AND ALINE U. ORTEN, PH.D., *Detroit, Michigan*

From the Department of Surgery, Wayne State University College of Medicine and the Detroit Receiving Hospital, Detroit, Michigan. *Supported by grants from the Research Corporation of Detroit Receiving Hospital, and the National Drug Company.*

IN 1944 Connor and Harvey [1] reported remarkable success in removing burn slough through the application of pyruvic acid in a starch paste at pH 1.9. The acid appeared to develop a plane of cleavage between living and dead tissue rather than to disintegrate the latter as proteolytic enzymes do. The underlying fat was reported to have been uninjured and ready to receive grafts. Controlled studies in human volunteers by Sulzberger, Kanof and Baer [2] also showed that pyruvic or phosphoric acids in a variety of bases accelerated the separation of burn slough. Only Lam and Puppendahl [3] reported that the acid behaved no differently from distilled water.

When respected investigators endorse a form of therapy, it is puzzling that fifteen years later the method is unused although the problem of non-operative burn debridement has not been solved otherwise. The question to be answered was whether the inconvenience of the technic explained its neglect or whether the results were disappointing. Our study of acid debridement was in three phases: first, in rats; second, in human volunteers; and third, in patients.

STUDIES IN RATS

Depilated Sprague-Dawley rats under general anesthesia received two full-thickness scalds on one side of the body and two full-thickness metal-contact burns on the other side.* Three days later the rats were reanesthetized, restrained in Melmac plaster casts that encompassed the forelegs and thorax, and then placed in inclined plastic containers. General anesthesia was maintained throughout. Three hundred burns were observed, and the findings were as follows:

(1) Detachment of burn slough was clearly related to the hydrogen ion concentration. (Fig. 1.) In an aqueous solution of phosphoric acid at the pH range of 2.5 to 2.6, sloughs became detached in one piece within twenty-four hours and a healthy base remained. At pH below 2.5 there was not only debridement but also injury. The surrounding skin acquired a vitreous appearance and soon ulcerated; thrombosis of the vessels in the base of the defect occurred. At pH above 2.6 more time was needed to achieve debridement, and at pH greater than 2.8 slough detachment failed to occur within three days.

(2) Aqueous solutions of phosphoric, pyruvic, lactic and citric acids performed similarly at the same hydrogen ion concentration, indicating that the hydrogen ion was the active portion of the molecule. Acetic acid, however, had a specific destructive effect upon the rat's skin, erosion occurring even at pH 3.

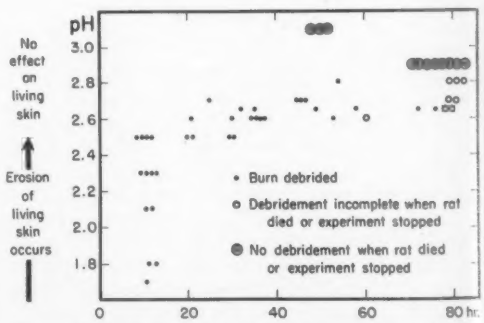

FIG. 1. The relation of hydrogen ion concentration in phosphoric acid solutions to effectiveness and speed of debridement and the erosion of unburned skin.

* Full details of all experimental methods may be obtained on writing to the authors.

(3) Scalds and dry thermal burns reacted similarly to acid debridement.

(4) The time interval between thermal injury and immersion in the acid bath influenced the effectiveness of acid debridement. Burns which were thirty-six hours old debrided more slowly than three to four day old burns. Those produced immediately before immersion were completely unaffected by exposure to acid for three days. The explanation probably is that with time the slough weakens its bonds to the surrounding skin. The acid must separate the slough at the periphery before it can undermine the base.

(5) Rats under hypothermia (rectal temperature, 22°C.) were debrided at the same rate as rats with normal body temperature. Erosion of unburned tissue at pH below 2.5 took place at equal or greater speed.

(6) Rats immersed in acidic starch paste were debrided at hydrogen ion concentration 2.1 without erosion of unburned tissue. The explanation is that the hydrogen ions do not diffuse as rapidly through the starch as they are buffered by the wound and skin of the rat; hydrogen ion concentration paper applied directly to the wound indicated pH 3.5.

STUDIES IN HUMAN VOLUNTEERS

Burns were produced by passing steam (109°C.) through a copper cylinder which was held in contact with the skin for intervals from five to 150 seconds. Some were treated by exposure and others with vaseline dressings. After seven days debridement was attempted. Pyruvic and phosphoric acids were used at hydrogen ion concentration levels varying from pH 1.6 to 6.0, in both aqueous and starch media. Aqueous solutions were applied by gluing inverted ileostomy bags over the burns, while starch pastes were applied by gluing centrally perforated plastic jars over the burns.

The results in eight pairs of symmetrically placed burns were as follows (Table 1):

(1) The more acid the aqueous solution, the less debridement took place. Exposure to solutions ranging from pH 1.6 to 2.4 produced no detachment of the slough during six days of continuous exposure. The acid toughened and tanned the eschar. Considerable pain was experienced. Exposure to aqueous solutions at pH 3.3 to 5.7 produced inconsistent partial debridement in six days.

TABLE 1
RESULTS IN EIGHT PAIRS OF SYMMETRICALLY PLACED BURNS IN HUMAN VOLUNTEERS

Duration of Contact with Copper Burner (sec.)	Treatment	pH	Days of Treatment	Result
100	H_3PO_4 in PSS*	1.6	5	No debridement
100	H_3PO_4 in PSS	1.9	5	No debridement
40	H_3PO_4 in PSS	1.9	6	No debridement
40	H_3PO_4 in PSS	2.4	6	No debridement
60	H_3PO_4 in H_2O	1.9	6	No debridement
60	H_3PO_4 in PSS	3.3	6	Moderate debridement
150	Na_2HPO_4 and NaH_2PO_4 in H_2O	5.7	4	Moderate debridement
150	NaH_2PO_4 in water	4.5	4	No debridement
60	Pyruvic acid in PSS	1.9	7	No debridement
60	PSS alone	6.8	7	No debridement
60	Pyruvic acid in starch	1.9	7	No debridement
60	Starch alone	6.0	7	No debridement
5	H_3PO_4 in starch	1.9	9	No debridement
5	Starch alone	6.0	9	Complete debridement
60	H_3PO_4 in starch	1.9	9	No debridement
60	Starch alone	6.0	9	Complete debridement
5	H_3PO_4 in starch	1.9	4	Complete debridement
5	H_3PO_4 in starch	1.9	4	Complete debridement

* 0.85 gm. NaCl per 100 ml. H_2O.

(2) Starch paste at pH 1.9 debrided one pair of superficial burns. In two other pairs of deep burns no effect was noted in the ones exposed to pH 1.9, while complete debridement occurred in the starch controls at pH 6. The latter were macerated and infected, and bacterial enzymes probably played a role.

CASE REPORTS

CASE 1. J. H., a seven year old girl, suffered 60 per cent full-thickness burns when her clothes caught fire. On the fourteenth day a drip of 15 gallons a day of phosphoric acid in isotonic sodium chloride (pH 2.0) was begun; the solution flowed through six perforated catheters beneath the dressings. After forty-eight hours respiration appeared acidotic; hydrogen ion concentration of the blood was pH 7.2, and urine (although free of acetone) had a hydrogen ion concentration of pH 4.6. It seemed obvious that ion exchange was taking place at the burns and wounds which had been surgically debrided during the preceding week. Sodium lactate was administered intravenously, and acidosis was overcome. After three days of treatment the burns were inspected. The slough was firm and leathery; even at the margins there was no loosening of its

attachments. The treatment was discontinued because of the difficulties and risks involved and the disappointing progress. The child ultimately recovered.

CASE II. J. J., a seventy-five year old man, received 30 per cent full-thickness burns when a steam pipe exploded. Eighteen days later his burns were crosshatched at intervals of 1 cm.; this was painlessly performed using the Stryker oscillating motor with a shimmed blade attached to it. A plastic trough was slung between the side rails of his bed, and 10 gallons of phosphoric acid-starch gel at pH 2.0 was poured into it. The starch gel was replaced twice daily. After four days the treatment was discontinued. The slough was soft but showed no separation from its underlying attachments. The patient died on the thirty-fifth day after injury.

COMMENTS

Whatever the merits of non-operative debridement of burns may be, it appears that acid debridement has little to contribute. When acid in starch paste is in contact with the body, it is soon buffered to a higher hydrogen ion concentration, and whatever it accomplishes is probably the result of maceration and infection. Aqueous acid solutions do not loosen the slough, and they bring about severe systemic acidosis if the patient has open wounds. The disagreement between our findings and carefully controlled studies of Sulzberger et al. [2] might be explained by the fact that they employed a low temperature (67°C.) burn. We have found that burns at this temperature do not denature the collagen of the dermis in the same way as hotter burns do, so that they fail to stain differentially in the modified Verhoeff technic of Hinshaw and Pearse [4].

SUMMARY AND CONCLUSIONS

1. Experimental burns in rats were rapidly and safely debrided by the proper concentration of a number of weakly dissociating acids.

2. Experimental burns in human volunteers were not debrided by aqueous solutions of phosphoric or pyruvic acids at pH 1.6 to 1.9. Sporadic debridement occurred in aqueous solutions at a higher hydrogen ion concentration, in starch-acid gels and starch gels without acid.

3. Attempts at debriding one patient with an aqueous acid solution and another with a starch-acid gel were unsuccessful. The former cannot be safely employed because of marked ion exchange between the patient and the acid bath.

4. The information obtained from experimental burns in animals is commonly of value only to veterinarians.

Acknowledgment: The authors wish to express their appreciation of the technical assistance of Mr. Walter Farris.

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Early Management of Burns

PRIMARY EXCISION AND HETEROGRAFTING WITH EARLY AUTOGRAFTING

LACY STALLINGS, M.D., ERIC KAHN, M.D., MITCHELL GOLDENBERG, M.D., I. H. SOKOLIC, M.D. AND JOHN M. HOWARD, M.D., *Philadelphia, Pennsylvania,* WITH THE TECHNICAL ASSISTANCE OF M. WINOKUR, B.A.

From the Albert Einstein Medical Center, Southern Division and Hahnemann Medical College and Hospital, Philadelphia, Pennsylvania. This project was supported in part by E. R. Squibb & Son and the U. S. Department of the Army.

THE present problem in the management of the severely burned patient is the adequate removal of the devitalized tissue and the subsequent covering of the wound with autogenous skin. Discouraged with the results of standard therapy of the extensively burned patient [*1*], an aggressive program is being evaluated along the following lines. This is a progress report and the authors are not yet ready to recommend the method as a procedure of choice.

The program which is being evaluated is (1) early standard treatment of the patient with parenteral and oral fluids and colloid, (2) delineation of the extent of third degree burn, (3) immediate or early excision of all or a major part of the burn under local anesthesia, (4) covering the open lesion with heterograft as a biological dressing, and (*5*) securing coverage with autografts as soon as feasible. Delineation of the third degree burn is accomplished by clinical means and corroborated by demonstrating the capillary circulation using a Woods' light and intravenous fluorescein [*2*].

Points 3, 4 and *5* in the program represent staged excisional débridement and autografting. This particular approach has the advantage of enabling liberal use of local anesthesia and if the occasion demands, light general anesthesia and analgesia. Immediate autografting is seldom performed because it prolongs surgery, produces additional blood loss when the patient is in precarious condition and requires a deeper anesthesia. Also, to be sure, patients with burns of 50 per cent do not have enough skin available for complete autografting. Heterograft skin from fetal calves was selected primarily because of its ready availability. The skin itself was lyophilized to enable long term storage.

Preliminary animal investigation was carried out to ascertain the properties of the fetal skin. In twenty-three dogs an area of *5* by 7 cm. was excised and the defect covered with heterograft skin. The animal was then observed to determine how long the grafted skin remained *in situ.* Arbitrarily, the end point was defined as that time when only 10 per cent of the original skin graft was still present. Using this criterion the heterograft remained approximately eight days, a range of five to thirteen days being noted. Adequate wound coverage lasted approximately four to five days. In two patients, 1 by 2 cm. skin defects were created and covered with heterografts. Duration of covering was from two to three weeks in these wounds. By the time the heterograft fell off these two wound defects, re-epithelialization had occurred to approximately *75* per cent.

The effect of heterograft covering on the bacteriology of wounds was investigated and early results appeared to show some evidence of wound sterilization. However, the results are not conclusive.

The problem of sensitization was next evaluated. In twenty animals the second set reaction [*3,6*] was evaluated in the following manner. Lyophilized heterologous skin from calf A was placed upon a *5* by 7 cm. wound defect of a dog host and its rate of slough observed. Three weeks later skin from the original calf donor and a second calf donor "B" was again placed upon the dog host and the rate of slough of the second grafts observed. No

second set reaction could be demonstrated. Skin grafts A and B seemed to slough at independent rates. These data would tend to indicate that no tissue sensitization occurs in the host animal. Using the hemagglutination technic of Boyden [4] and the passive cutaneous anaphylaxis test of Ovary [5], no evidence of increasing titer of circulating antibodies was noted.

Nine patients were treated with this type of approach. They ranged in age from one to eighty-four years. The degree of burn varied from 15 to 95 per cent. Three patients died during their hospital stay. The first was a fifty-six year old obese white woman who was admitted with a 75 per cent burn, the second was a seventy-two year old Negro woman with a 70 per cent burn, and the third was a twenty-six year old woman with a 95 per cent burn. The cause of death was renal failure in two patients and anesthetic catastrophe (general anesthesia) in one. A case history is included of one of the patients who died.

A fifty-six year old white woman weighing approximately 200 pounds was admitted to the hospital with flame burns of the entire body except for the palmar surfaces of the hands, a strip of the lower portion of the abdomen and perineum, and a portion of one leg. It was estimated that this patient had approximately a 75 per cent total third degree burn.

The patient was immediately treated vigorously for shock. On the following day a primary excision of the third degree burn of the entire anterior chest wall, including a bilateral simple mastectomy was performed. Fresh homografts were applied over the excised area. The patient was then placed on an ice blanket to maintain her temperature at approximately 94°F. Forty-eight hours later the patient was taken back to the operating room, the burn of the anterior abdominal wall, the right thigh and leg, and the right arm and forearm was excised. This was performed with the sparing use of local anesthesia. Blood loss was replaced using the weighed sponge technic. Hypothermia was continued but despite this the urinary output slowly decreased and six days after admission the patient was anuric; she died in renal failure. Perhaps more vigorous burn excision should have been carried out at an earlier date. The value of hypothermia therapy is also questionable.

The case histories of some of the patients who recovered are listed herein, demonstrating some variations of the basic approach we have assumed.

A forty-one year old Negro man had approximately a 25 to 30 per cent third degree burn of both legs. He was admitted in good physical condition. Oral and intravenous fluids were given to secure an adequate urinary output. On the second day after the burn approximately three quarters of the third degree burn was excised and the patient was covered by heterograft. Two days later an autograft was applied and approximately a 50 per cent take was secured. This patient is still hospitalized and has about 90 per cent skin coverage at the present time after the second autografting.

Another patient, S. A., a one year old white girl, was admitted with a 25 to 30 per cent second and third degree burn of the leg, perineum, arm, right hand and anterior abdominal wall. The patient was observed carefully over the first eight hours and treated primarily with oral fluids. When it was apparent that the urinary output was stable on the first day of admission, excision of the apparent third degree area was carried out and a heterograft applied. On the second postoperative day the patient was returned to the operating room. The heterograft was removed and autografts were applied. Approximately 80 per cent take was secured and the patient was returned twice more for autografting, getting complete coverage on the third autograft session.

The hospital course of four other patients treated successfully was similar to these. In no instance was full autograft coverage obtained at the first grafting session.

SUMMARY

It is still uncertain whether this clinical approach to the problem of the extensively burned patient will yield a higher survival rate. This program has not been universally successful. One of the initial aims, namely, reduction of the duration of hospitalization, unfortunately, has not been realized up to the present time. Nevertheless, primary excision of extensive burns and strategic employment of heterograft material does offer a positive program to the severely burned patient.

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DISCUSSION OF PAPERS BY DRS. GIMBEL, WEISSMAN, SCHIRLE AND ORTEN; AND STALLINGS, KAHN, GOLDENBERG, SOKOLIC AND HOWARD

T. G. BLOCKER, JR. (Galveston, Tex.): These papers have been rather outstanding. The work on excision of burns is an unsolved problem as yet, and I am sure the majority of you agree that it should be confined to patients with less extensive burns at the present time rather than those with large ones as far as general practice is concerned. We have tried all the débriding agents that have been proposed to date, including the pyruvic acids presented by Dr. Gimbel. So far we agree with the last statement in the protocol he presented to Dr. Fitts, "They are commonly of significance only to the veterinarian."

In consideration of the later problems in burn therapy, of importance in addition to nutritional care and relief of anemia, is cleanliness of the burn. We have developed a method on our service as an adjunct to surface care. A spray with a large nozzle on the end allows us to spray the patient with ordinary tap water from the faucet. We use a tub on an inclined plane which permits us to clean the areas without the apparent dialysis effect produced on immersion in a tub. The spray is of value both in the débriding stage and pregrafting stage. Following survey of our operating room by an engineer with a time and motion study we have installed an overhead circular frame from which the hose can be pulled for use on a patient. We have also developed for evaluation a disposable plastic tub, manufactured by the Union Carbide Company.

C. L. KIEHN (Cleveland, Ohio): There were so many facts brought out in these papers that it is impossible to discuss them all. However, I would like to talk about two things very briefly. One is the care of the donor site, which everybody seems to take for granted. The fact was mentioned that the donor site often becomes infected in chronic burn cases and consequently does not heal. However, it will not heal if a combination of infection and malnutrition is present or if dressings are badly placed and inadequate. When taking grafts from chronically ill patients it is best to take as thin a graft as possible; this is best done with a Blair-Brown knife. A combination of poor nutrition, thick grafts, introduction of infection from the recipient site, and donor sites which will not heal increase the surface of the wound. Therefore, great caution should be taken to avoid a thick graft, to apply the dressings properly with some type of emollient, usually Xeroform,® and massive pressure dressing. The grafts should be taken before the recipient site is exposed, so that the donor site will not become infected. Of course, the patient should be in the best nutritional state possible before grafts are taken. If the dressing is properly applied it should be left on for the time that it takes for the wound to epithelialize, which is anywhere from ten to fourteen days.

The second point I would like to make is on the early excision of burns. This can only be done with well demarcated burns when the area is less than 20 per cent of burn surface. In one case, a man was electrically burned, his clothes were set on fire and his trousers were burned off. There was a well demarcated area from the mid-thigh circumferentially down to the ankle. The devitalized tissue was excised down to the fascia on the seventh day after the burn. The area was then covered with postage stamp split skin graft taken from the chest wall, and massive Xeroform pressure dressings were applied. The first dressing was done in four days with complete take of all grafts. No further grafting was necessary, with the exception of a pedicle graft to the Achilles tendon, which was exposed at the time of the burn. If the defect is of such a size that you do not have enough autogenous skin, then homografts may be used with alternate pieces of autogenous grafts. Heterografts should never be used as they will be replaced by scar tissue contractures.

J. L. BELL (Chicago, Ill.): I think we as surgeons can eventually eliminate the problem of chronic burns by an aggressive attack on the wound. We try to teach our students that they should approach the treatment of burns in the same way they do any other open wound, with the same objectives. We found that some burns which are chronically infected will not heal beneath any type of dressing. These must be cleaned by rinsing as mentioned by Dr. Blocker. Even when grafts are applied and the area appears clinically clean, they will frequently not take well. We have had some success with open grafting in stubborn cases. On the trunk the exposure method for management of the donor site is much more satisfactory than trying to apply a heavy occlusive dressing.

The area of the donor site can be increased by subcutaneous injection of isotonic saline solution. This will temporarily make the patient fat, and round the contour of irregular surfaces.

For the acute burn, the late Dr. Harvey Allen advocated early excision in 1949. By early I mean within the first week; not as early as within the first forty-eight to seventy-two hours. By the end of the first week the surgeon should be able to delineate accurately a full-thickness burn. If a

whole thickness burn is present, the surgeon should try to visualize the phases that the patient has to go through before complete healing is achieved. We advocate surgical excision in such cases.

We rarely have had patients with burns over 50 per cent of the surface of the body; so my remarks are confined to the 20 to 30 per cent body surface burns. In such burns, if surgical excision is performed carefully within five days, autografts can be applied from an available donor site on the body. The wound should be closed with autogenous skin within two weeks of the time of the burning. This is our goal at the present time.

C. G. JOHNSTON (Detroit, Mich.): This is a gratifying set of papers. It is gratifying primarily in its inadequacies to settle the problem. We recognize that we have not licked the burn problem. We have tried many different methods of handling them; some that have been discarded are as good as the ones we are using today, but we are still trying to find better methods. Furthermore, in most areas we are doing less animal experimentation on burns; primarily because it is pretty difficult.

What has always bothered me about the immediate or early débridement of wounds or burns is the question of how deep to cut, and how to tell whether you are cutting away skin which does not need to be cut away? Burns are not always even, and in some areas there are tissues which will respond to healing and others which will not.

So far as I am concerned, this is difficult to tell immediately after a patient comes in, or even within twenty-four hours. There are other problems which must be taken care of first, such as the matter of shock and the administration of fluids. When we were on Kwajalein, we treated a great many patients with burns. Fortunately off the sickbay was a shower bath. We washed the burns with soap and warm water with good results. After some studies we did just before the war, we found a great deal of the pain associated with washing burns will result from the use of ordinary water or saline if the fluid is hot or cold. On the other hand, if the temperature of the fluid is the same as body temperature, the patient will stand the washing of wounds and burns well.

I. FELLER, (Ann Arbor, Mich.): These papers and the discussions describe the method that we are all trying to undertake to improve the treatment of burns. As you know, twenty to thirty papers on the very same topic appear in the literature every month. What we are lacking is a method of evaluating the treatment that exists, and the mortality has been a method of measuring the effectiveness of treatment. Unfortunately this just tells us about the ability to save the patient in certain borderline cases. The question then comes up, "How about the evaluation of the patients who survive?" To help in this evaluation we have been undertaking a study to use morbidity factors to evaluate the effectiveness of burn therapy with the methods we already have at hand. Morbidity factors to be considered include the number of days required to treat burns, certain magnitudes, number of admissions and readmissions for specific burns.

The question we can ask of ourselves is how many days should we take to treat burns of a specific magnitude?

MARTIN ALLGÖWER (Switzerland): I have a remark to make about débridement. I think we have no other test object, just animal skin. We should not be too reluctant to accept pig skin for this purpose.

We had plenty of opportunity in Germany to observe burns in man following metallic burning, and we had exactly the same cleaning time. I think the animal burn has exactly the same value. With an extensive burn of third degree depth you get exactly the same cleaning time.

Of interest is that if you have a burn comparable to one in a human subject, you get about the same cleaning time.

J. MITHOEFER (Cooperstown, N. Y.): Dr. Sokolic, is the study you have reported a purely experimental study or are you advocating the use of heterografts for covering the areas after excision of burns rather than banked homograft skin? We know skin will remain viable for periods of six weeks, and homograft skin when available might last somewhat longer than heterografts. I have had no experience with heterografts, but I wonder if you can tell me whether they become vascularized. If they do not, and just remain as a dressing, I do not believe the second set response would be of any significance, because I do not believe there would be any.

Another question I want to ask is whether these heterografts were used on any patients who did not have lymphomas. We know that patients with chronic uremia or far advanced cancer, have a specific anergy which allows them to accept either skin or kidney homografts for a longer period of time than normal subjects.

I. H. SOKOLIC (closing): I would like to point out that at present this is strictly an experimental study. We are not advocating this method of treatment. We are not sure it is any good. We do not think it does any harm. We have had some experience with homografts, particularly the lyophilized form. In our experience they last no longer than heterograft material. To be sure their rejection may not be as violent. The second set reaction was an important problem. We do not believe that our grafts become vascularized. We have some conflicting data on this at the present time, and I would rather not go into it. However, we are fairly certain that they do not become vascularized with red cells

circulating through the skin. To be sure, the second set reaction will not occur unless vascularization does occur. This is one of the strongest points we have for believing that the skin does not receive blood cells from the host. We have run a number of serologic studies on the circulating serum and have demonstrated no appreciable rise in antibodies.

We have not tried the heterograft skin on patients who did not have lymphomas. We have used the skin on some chronically infected wounds and have repeatedly reapplied the skin; it does seem to have a cleansing action. On relatively clean wounds of patients with vascular ulcers the skin can last as long as five or six days.

Dextran Therapy in Severe Burns

RESULTS IN 246 CASES

B. W. HAYNES, JR., M.D., *Richmond, Virginia*

From the Department of Surgery, Medical College of Virginia, Richmond, Virginia. This study was supported in part by funds from Army Contract No. DA-49-007-MD-904.

IN 1954, Evans and Martin [1] reported the use of dextran in 123 burned patients admitted to the Burn Service of the Medical College of Virginia Hospital. This experience suggested that dextran was an effective agent for prevention and treatment of burn shock, and no reactions to it were observed. Since their report, the policy of treatment has emphasized dextran for colloid replacement to an even greater extent than before. The Evans formula has been used as a clinical guide, giving dextran and blood in approximately a 2:1 ratio for burns generally exceeding 25 per cent of body surface area, and with significant third degree burn. For most burns approximating 20 per cent, emphasis has been placed upon dextran as the sole colloid for blood volume replacement. Details of the therapeutic approach have been published previously [2]. The present paper attempts to review our experience summarizing clinical observations on the effectiveness of dextran in the early management of burns.

TABLE 1
MORTALITY ACCORDING TO PER CENT OF BURN

	Body Surface Area (%)		
	1–25	26–50	51–100
Total no. of patients	114	84	48
No. of adults	59	48	30
No. of deaths	19	32	29
Mortality (%)	32	67	97
No. of children (12 yr. and under)	55	36	18
No. of deaths	7	21	17
Mortality (%)	13	58	94
Deaths in adults (in 2 days)	0	2	4
Mortality (%)	0	4	13
Deaths in children (in 2 days)	1	0	2
Mortality (%)	2	0	11

The dextran used was commercial, a product of several American companies. Dextran is a polymer of glucose and the solution used was 6 per cent in saline solution, having an average molecular weight approximating 70,000 with a range of 25,000 to 200,000. It acts as a plasma volume expander, by virtue of its osmotic pressure effects. Excellent reviews of the experimental and clinical studies of dextran are available [3,4]. We have used dextran successfully for the treatment of shock from wounds [5]. Extensive use during the Korean war demonstrated that dextran had considerable usefulness in managing shock seen in battle casualties [6].

The 246 patients in the present study ranged in age from six months to ninety-five years old, and were equally divided by sex. There were 109 children under twelve years of age, and 137 adults. The area of burn varied from 8 to 100 per cent and many patients had significant third degree burn. Table 1 summarizes the patients according to per cent of burn and mortality.

Mortality rates were comparable to those of Bull and Fisher [7] and did not change significantly during the years of the present study. A mortality of 33 per cent in adults with 1 to 25 per cent burn is primarily a reflection of advanced age.

Dextran has been given in amounts up to

6,000 cc. during the first forty-eight hours after injury. Characteristically, the initial response to dextran infusion has been good, as evidenced by circulatory improvement. The patient with hypotension following burn responded promptly to infusion and associated improvement in peripheral circulation and pulse volume was noted. Although many patients received whole blood, the majority were treated initially with dextran. The efficacy of the shock therapy is attested to by the fact that only nine patients in the entire series died during the first two days after injury. Only two patients died on the day of injury. The following case report summarizes a patient's typical response to treatment.

I. L., a thirty-one year old woman, was admitted to the Burn Service of the Medical College of Virginia Hospital two hours after receiving flame burns on 55 per cent of body surface area, of which 30 per cent was third degree. She was not in shock on arrival, and venostomy was performed and dextran administered. Figure 1 summarizes her fluid therapy and response during the first forty-eight hours after injury. The administration of 1,000 cc. of dextran was followed by an improved urinary output from 15 to 30 cc. per hour, and 500 cc. of whole blood plus 800 cc. of dextran increased the output to 35 cc. per hour. Saline solution was given followed by a progressive decrease in urinary output. The administration of 500 cc. of blood was followed by a prompt rise in urinary volume although a prompt fall occurred when 5 per cent dextrose in water was added. Additional dextran caused a rise in urinary volume, which stabilized at 35 cc. per hour with the additional help of saline solution. Her course in the hospital was stormy. She required multiple transfusions and dressings, and four split skin grafts were performed. She recovered and improved, and was discharged from the hospital approximately six months after entry.

As indicated by this case report, renal function following dextran therapy has been quite satisfactory. Urinary output was well maintained, and blood urea nitrogen was rarely elevated during the first two days. The patient with a successfully treated burn ordinarily excretes 25 to 50 cc. or more of urine hourly during the two days after injury, and dextran has been most helpful in maintaining this output. In many instances, infusion of 500 cc. of dextran in thirty minutes to an oliguric patient resulted in increased urinary volume. This test

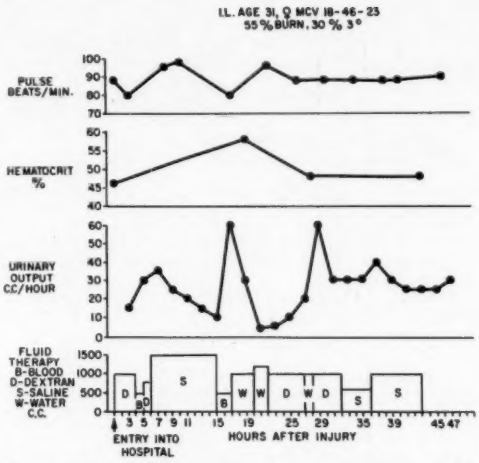

FIG. 1. This figure summarizes the response of a severely burned patient to dextran therapy. Note the relationship between dextran infusion and urinary output.

has been helpful in differentiating oliguria due to hypovolemia from that due to renal damage. Renal failure, however, was seen infrequently and usually associated with prolonged hypotension. As a rule, correction of hypotension improved urinary output so that renal failure was an uncommon problem. The presence of pre-existing renal disease may predispose to renal failure also. In instances when adequate urinary output was difficult to maintain, evidence of hypertensive cardiovascular renal disease was commonly found. The specific gravity of the urine is elevated after dextran and may be 1.040 or more, reflecting the concentration of small molecules excreted in the urine. Osmotic diuresis has been shown to be possible following burns and despite antidiuresis [8]. It seems likely that tubular lavage with dextran may be beneficial to the kidney. The renal threshold for inert molecules is about 45,000 molecular weight. Dextran solution contains a large number of smaller molecules which readily pass through the glomerular filter, and increase urinary volume by their osmotic effects within the tubule. Dextran has an advantage over urea as an osmotic diuretic in that in addition it expands plasma volume. We have detected no untoward effects on the kidney due to dextran therapy either clinically or pathologically.

Dextran may produce interference with typing and crossmatching of blood because of a

TABLE II
COAGULATION STUDIES AFTER DEXTRAN

Patient	Weight (kg.)	Age (yr.)	Date of Burn	Date of Admission	Per cent of Burn		Dextran (cc.)			Bleeding Time		Clot Retraction		Prothrombin Concentration		Platelet Count		Remarks
					3°	2°	1st 24 hr.	2nd 24 hr.	Total	Min.	Date	Time (hr.)	Date	%	Date	Cells/ cu. mm.	Date	
M. S.	26.3	8	11/20	11/20	4.5	12.25	450	250	700	1.5	11/20	None in one day	11/21	50	11/20	131,000	11/20	Discharged 1/9/59
										1	11/22	5	11/22	50	11/22	274,000	11/22	
										3 sec.								
										8	11/25	1	11/25	38	11/25	154,000	11/25	
										45 sec.								
														43	12/7	.....	...	
S. C.	11	15 mo.	11/21	11/21	4	11	175	75	250	2.5	11/21	8	11/22	60	11/21	314,000	11/21	Discharged 12/1/58
										2	11/22	1	11/26	75	11/26	233,000	11/22	
										55 sec.								
										2	11/26	.....	...	..	...	226,000	11/26	
P. R.	13.3	3	11/10	11/10	12	16.5	725	250	975	1	11/13	.....	...	33	11/13	129,000	11/14	Died 12/16/58
														27	11/15	234,000	11/17	
														33	11/18	.....	...	
														33	11/20	.....	...	
														33	11/24	.....	...	
														38	12/2	.....	...	
														60	12/7	.....	...	
														25	12/12	.....	...	
J. B.	23.6	8½	11/12	11/12	8	26	750	400	1,350	3	11/15	4	11/18	60	11/14	204,000	11/18	Healed satisfactorily
										2.5	11/18	.....	...	43	11/17	.....	...	
														30	11/18	.....	...	
														33	11/21	.....	...	
														33	11/24	.....	...	
														43	12/3	.....	...	
														50	12/5	.....	...	
														60	12/18	.....	...	
														60	12/21	.....	...	
D. R.	12.5	3	2/1	2/1	26	24	950	350	1,300	1.5	2/1	1	2/1	33	2/1	.....	...	Died 2/4/59
										2.25	2/3	2	2/3	43	2/3	81,000	2/3	
L. W.	62.7	67	2/3	2/3	15	18	2,450	850	6,500	4.5	2/3	2	2/3	60	2/3	260,000	2/3	Died 2/28/59
										1.25	2/5	.....	...	75	2/5	148,000	2/5	
										2	2/9	.....	...	60	2/9	194,000	2/9	
L. B.	50	78	2/8	2/8	24.5	19.5	1,000	1,000	2,000	2	2/9	15	2/8	100	2/8	.....	...	Died 2/10/59
										45 sec.	...	16	2/9	30	2/9	.....	...	
C. H.	13.8	23 mo.	2/6	2/6	35	21	500	400	900	1	2/6	14	2/9	75	2/6	77,000	2/9	Died 2/18/59; stools positive for blood 2/8, 2/9, 2/14; bleeding from forehead wound, 2/7
										2.5	2/9	.....	...	43	2/9	91,000	2/10	
										1	2/10	.....	...	50	2/10	.....	...	
										1	2/11	.....	...	..	...	.....	...	
R. H.	9	1	2/6	2/6	8	6.5	250	65	315	1.5	2/6	4	2/9	33	2/9	208,000	2/9	Discharged 4/27/59
										1	2/9	.....	...	..	...	25,000	2/11	
										4	2/11	.....	...	..	...	.....	...	
T. J.	10	1½	2/22	2/22	5	30.5	150	160	310	1.5	2/22	.....	...	38	2/22	349,000	2/23	Died 3/10/59; gastrointestinal bleeding 2/28; stools positive for blood 3/2, 3/3, 3/9, 3/10
										2	2/24	1	2/24	..	...	321,000	2/24	
										2	2/27	1	2/27	..	...	300,000	2/28	
														8	3/10	.....	...	
R. H.	15.4	3	12/6	12/6	25	30	455	250	705	2.5	12/6	1.5	12/7	60	12/7	529,000	12/9	Died 12/24/58; Pseudomonas septicemia
										5	12/7	1	12/1	100	12/8	349,000	12/1	
										45 sec.								
										2.5	12/8	.....	...	33	12/11	.....	...	
														38	12/15	.....	...	
										2.5	12/11	.....	...	60	12/17	.....	...	
														43	12/22	.....	...	
H. W.	12	2	11/16	11/16	4.5	10	600	....	600	2	11/18	4	11/18	50	11/18	184,000	11/18	Discharged 12/27/58
										45 sec.								
										3	11/21	24 min.	11/21	60	11/21	285,000	11/21	
P. E.	8.7	10 mo.	11/27	11/27	3	11.7	95	....	95	2.5	11/28	40 min.	11/29	38	11/28	282,000	11/28	Discharged 1/3/59
										2	11/29	.....	...	..	...	264,000	11/29	
B. W.	16.8	4	12/2	12/2	...	15	250	....	250	3.5	12/4	3	12/2	50	12/2	205,000	12/3	Discharged 1/28/59
										3	12/8	1	12/4	50	12/8	180,000	12/5	
												2	12/8	..	...	317,000	12/8	
E. J.	48	58	12/27	12/27	68	0	2,000	700	4,040	5	12/30	1	12/29	43	12/28	85,000	12/29	Died 1/5/59
										3.5	1/2	1	1/1	50	12/31	.....	...	
E. J.	64.3	40	10/31	10/31	31	0	2,000	500	3,000	6	11/3	.....	...	75	11/3	33,000	11/4	Died 11/9/58
										3.5	11/4	.....	...	33	11/7	122,000	11/7	

TABLE II (*Continued*)

COAGULATION STUDIES AFTER DEXTRAN

Patient	Weight (kg.)	Age (yr.)	Date of Burn	Date of Admission	Per cent of Burn		Dextran (cc.)			Bleeding Time		Clot Retraction		Prothrombin Concentration		Platelet Count		Remarks
					3°	2°	1st 24 hr.	2nd 24 hr.	Total	Min.	Date	Time (hr.)	Date	%	Date	Cells/ cu. mm.	Date	
R. G.	78.4	29	1/23	1/23	50	26	3,000	1,500	7,000	6	1/23	1.5	1/23	50	1/23	295,000	1/23	Died 2/11/59
										2.5	1/25	1.5	1/26	43	1/25	100,000	1/26	
										2	1/27	1.5	1/27	..	...	.....	...	
W. A.	80	19	2/25	2/25	4	30	1,500	2,000	3,500	2	1/28	1.5	1/28	38	1/28	51,000	1/28	
										2.5	2/25	1.5	2/25	33	2/27	130,000	2/26	Healed satisfactorily
										3	2/28	None in	...	43	2/28	48,000	2/28	
										3	3/3	one day	2/28	50	3/2	82,000	3/3	
												48	3/2					
I. Y.	62	49	3/9	3/9	15	19	1,500	1,000	3,000	3.5	3/9	1	3/9	60	3/9	211,000	3/9	Died 3/14/59
												1	3/12	60	3/12	106,000	3/12	
L. K.	21.7	7	3/2	3/2	8.25	10.125	750	250	1,000	3.5	3/21	1	3/21	60	3/21	350,000	3/21	Healed uneventfully
										1	3/23	1	3/23	50	3/23	256,000	3/24	
										15 sec.								
										4	3/26	1	3/26	50	3/26	230,000	3/26	
										5 sec.								
																318,000	3/30	
N. B.	40	85	3/23	3/23	10	24.25	1,350	900	3,550	3.5	3/23	1	3/23	60	3/23	199,000	3/23	Died 3/29/59; bleeding through mouth
										4	3/25	1	3/25	43	3/25	86,000	3/25	
										4	3/28	.....	...	..	...	.....	...	3/29 (just before death)
										15 sec.								
E. R.	70	62	3/28	3/28	8	2	500	....	500	5	3/28	1	3/28	60	3/28	.....	...	Healed uneventfully
										10 sec.								
										1	4/1	.....	...	43	3/30	.....	...	
										15 sec.								
														38	4/16	.....	...	
														18	4/18	.....	...	
														19	4/19	.....	...	
														27	4/20	.....	...	
J. B.	14	5	3/28	3/28	22	2	500	350	850	2	3/28	2	3/28	70	3/28	.....	...	Died 4/18/59
										15 sec.								
										3	3/30	.....	...	..	...	348,000	3/30	
										50 sec.								
										1	4/3	2	4/3	100	4/3	350,000	4/3	
										15 sec.								
L. D.	58.9	58	4/14	4/14	11	7.75	1,000	500	1,500	.....	...	Normal	4/14	43	4/14	.....	...	Healed satisfactorily
										2	4/16	Normal	4/16	60	4/16	61,000	4/16	
										15 sec.								
										3	4/20	1	4/20	50	4/20	72,000	4/20	
S. C.	69.5	42	4/18	4/18	39	1.5	2,000	1,000	4,000	.....	...	Normal	4/18	75	4/18	.....	...	Died 5/12/59
										5	4/20	Normal	4/20	43	4/20	73,000	4/20	
										15 sec.								
										1	4/23	1	4/23	43	4/23	38,000	4/23	
										45 sec.								
																134,000	4/25	

tendency to produce agglutination of red blood cells. Ordinarily, a blood sample was drawn before dextran was given. However, retyping after dextran has presented no serious difficulty. In no patient in the series did a major reaction to transfusion develop.

The serum protein level fell routinely following dextran therapy. It was not uncommon to see total levels of 4.5 gm. per cent (2.5 albumin and 2.0 globulin) on the second day after injury. These values rose approaching normal as dextran was eliminated. The majority of dextran is excreted through the urine and a small amount is slowly metabolized [3]. The rise in serum protein follows the renal excretion of dextran. Although the fall in serum protein is largely a dilutional phenomenon, there is some evidence to suggest that the serum albumin may actually leave the circulation after dextran therapy [3]. In patients in the present study, the serum albumin commonly fell more than the serum globulin during the early days after treatment. (Fig. 2.) The serum globulin level recovered more rapidly than the serum albumin level, assuming a larger per cent of the total presumably due to increased production of antibodies, globulin in nature. Electrophoretic studies have shown the increased globulin to be

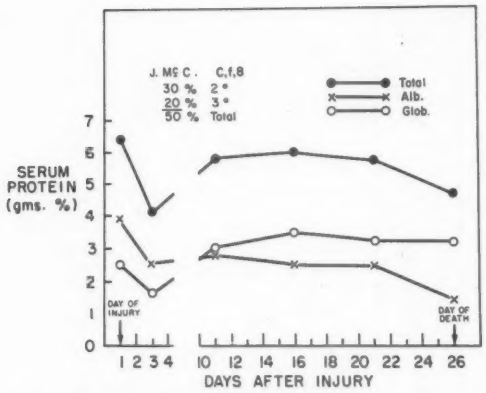

FIG. 2. Note the sharp fall in serum albumin and serum globulin after dextran therapy. The recovery of serum globulin in excess of albumin is due primarily to globulin production, chiefly gamma globulin.

chiefly gamma globulin. Wound healing in experimental animals is not delayed by dextran [3]. Serum protein changes produced no detectable ill effect on the patients in this series. It is worthy of note that blood sugar determinations after dextran therapy by the Anthrone method may show extremely high values. Values of 1,000 mg. per cent are not unusual. The use of the glucose oxidase method, however, eliminates this difficulty since it is specific for glucose.

Anaphylactic reactions have been reported following the administration of dextran to normal human volunteers [3]. These reactions have varied from mild to severe. Itching, urticaria, pain in the joints, respiratory distress and vasomotor collapse have been described. No patient in this series, however, has shown any evidence of an allergic reaction to dextran. It seems likely that the body's response to injury protects the patient from allergic reactions. Although the nature of this phenomenon is not clear, we do not hesitate in administering dextran to any severely burned patient.

Studies in human volunteers have demonstrated that dextran may produce prolonged bleeding [9]. Significant increases in duration of bleeding have been observed in 42 per cent of 163 subjects studied after receiving 1,000 cc. of dextran. Eight per cent of the volunteers bled in excess of thirty minutes. The maximal effect was three to nine hours after infusion, and was believed to be due to coating of platelets by dextran thus interfering with their disintegration and release of thromboplastin. Other clotting elements do not appear to be affected by dextran. Comparison of dextrans of different molecular weights showed that those of highest molecular weight (190,000 to 260,000) had the most marked effect in prolonging the bleeding time [9,10]. On this basis, the safety of dextran has been seriously questioned.

The patients in this series have been examined with the data previously described in mind. Of the 246 patients, prolonged bleeding was observed from some route in eighteen. Bleeding was evidenced chiefly by blood in vomitus or tarry stools, and with one exception was not massive. The exception was a child with a bleeding rectal polyp who had grossly bloody stools for four successive days. The child died of septicemia, however. Of the patients examined, none demonstrated prolonged bleeding time. However, three showed low prothrombin concentrations (23 per cent, 38 per cent and 43 per cent) and one had a low platelet count (48,000 per cu. mm.). Low platelet counts (50,000 and 100,000 per cu. mm.) and low prothrombin concentrations (40 to 60 per cent) are common after severe burn injury but are uncommonly associated with excessive bleeding.

To further clarify this problem, studies of bleeding time, clot retraction, prothrombin concentration (Quick's one-stage method) and platelet count (Rees-Ecker method) were performed on twenty-five severely burned patients before and at intervals after dextran therapy. Table II lists the results of this study. In no instance was the bleeding time prolonged beyond ten minutes, and in no patient did bleeding of serious consequence develop. Three patients who demonstrated some bleeding alteration are described.

C. H. was noted to have stools positive for blood on the second, third and eighth day following burn injury. Bleeding from a forehead wound was observed on the first day. Although the bleeding times were normal, a fall in prothrombin concentration from 75 to 50 per cent was noted, and a low platelet count observed. It seems likely that the severity of the injury was responsible for depression of liver function and a falling prothrombin concentration. Severe injury may be associated with a low platelet count. Since the clotting defect produced by dextran is prolonged bleeding time, there seems to be no reason to incriminate dextran in this patient.

T. H. was also observed to have stools positive for blood on the eighth, ninth, fifteenth and six-

teenth day following injury. He received no dextran after the second day, and all bleeding times before and after administering dextran were normal, as were the platelet counts. However, on admission the prothrombin concentration was observed to be only 38 per cent, and on the day of death (sixteen days after injury) it had fallen to 8 per cent. There is no reason to believe that dextran was responsible for these changes. Death was due to overwhelming infection, not hemorrhage.

N. B. experienced one episode of hematemesis shortly before death six days after injury. Falling platelet count and prothrombin concentration were observed during the hospital course. Bleeding times were repeatedly normal, however. It seems likely that severe injury was responsible for the falling prothrombin concentration and platelet count and may have been influential in causing the bleeding.

The previous data suggest that dextran does not produce significant bleeding in patients with severe burns. Neither significant bleeding in the present series nor significant alteration of bleeding time in the twenty-five patients studied specifically for bleeding has been observed. Apparently the burned patient is protected in some manner from the prolonged bleeding seen in normal human volunteers.

SUMMARY

1. Two hundred forty-six burned patients have been treated with dextran and blood for colloid replacement. In my opinion, dextran is an effective agent for circulatory maintenance after severe burns when used judiciously with whole blood. Many patients with 25 per cent burn or less are well treated using dextran as the sole colloid.

2. Dextran has been administered in amounts up to 6,000 cc. in forty-eight hours with no allergic reactions observed.

3. Dextran was most useful in maintaining a good urinary output, due to its effectiveness as a plasma volume expander and an osmotic diuretic.

4. Although dextran has been incriminated as an agent causing prolonged bleeding in human volunteers, no patient in the present series demonstrated prolonged bleeding due to dextran. A controlled study of twenty-five burned patients receiving dextran showed no evidence of prolonged bleeding time. In no patient was hemorrhage the cause of death.

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Relative Lack of Efficacy of Fluid Therapy

COMPARISON OF FLASH BURNS AND SCALDS IN MONKEYS

CHARLES L. FOX, JR., M.D., SIGMUND E. LASKER, M.S. AND JAMES M. WINFIELD, M.D.,
New York, New York

From the New York Medical College, Flower and Fifth Avenue Hospitals, New York, New York. This study was supported in part by Defense Atomic Support Agency, Department of Defense, Washington, D. C.

Of all forms of trauma, an extensive thermal burn is one of the most devastating. For some years our group has been conducting clinical and experimental studies to aid such victims.

The early treatment of burns begins with fluid therapy based in part upon clinical observation, but primarily upon research in lower animals. Contrary to the general belief in the efficacy of fluid therapy and despite alleged advances in fluid therapy, two recent reviews [*1,2*] have emphasized the slight improvement in reducing mortality rates during the past fifteen years. Perhaps this study will explain this serious discrepancy.

Careful reappraisal shows that many, if not the majority, of fatal burns in man are caused by flame or flash burns, not scalds. Accordingly, we utilized flash burns in monkeys and compared them with scald burns in terms of clinical appearance, fluid and electrolyte shifts, and most important, the response of each to fluid therapy.

The monkey was selected because it is an animal phylogenetically related to man; its relatively large size facilitates more exact clinical observation.

EXPERIMENTAL PROCEDURE

Minimal Thermal Trauma and Appearance of the Burns. The minimal thermal trauma necessary to produce a "full-thickness injury" (injury to all layers of the skin) was determined by graduated exposures of limited areas. The animals with non-fatal burns were observed for several weeks to establish the thermal trauma needed to injure all the layers of the dermis so that regeneration did not occur.

The scald initially produces blanching of the skin. There is loss of elasticity and subcutaneous edema forms gradually during the succeeding several hours. When a part of the body such as the hand is scalded in water, edema will cause the fingers to separate widely and typical blisters filled with straw-colored fluid are formed.

The appearance of the flash burn is different. (Fig. 1.) The brief 0.7 second exposure to heat over 1,000°C. causes slight charring of the skin and steam blebs are formed as water is driven rapidly out of the skin. The general appearance is dark brown, with loss of elasticity. Only slight edema (mostly in the underlying muscles) develops under the skin that is burned, but edema appears under the contiguous unburnt skin.

Minimal Surface Involvement to Produce Fatal Injury. Experiments were performed next to determine the smallest amount of body surface area which needed to be exposed to either of the above burns to cause death of most of the animals within twenty-four hours. Utilizing a graduated increase in involvement of surface area, there was a mean survival time of twelve hours when the scald involved the trunk to the level of the xiphoid process and both of the lower extremities with the exception of the protected genitalia. These regions totalled *55* per cent of body surface area. Ether anesthesia was used.

With the magnesium flash two exposures, one anterior and one posterior, were needed. Fluothane® anesthesia was used. The mean survival time was *1.5* days when the anterior trunk from the mid-chest to the symphysis pubis, and the posterior trunk from the scapulas

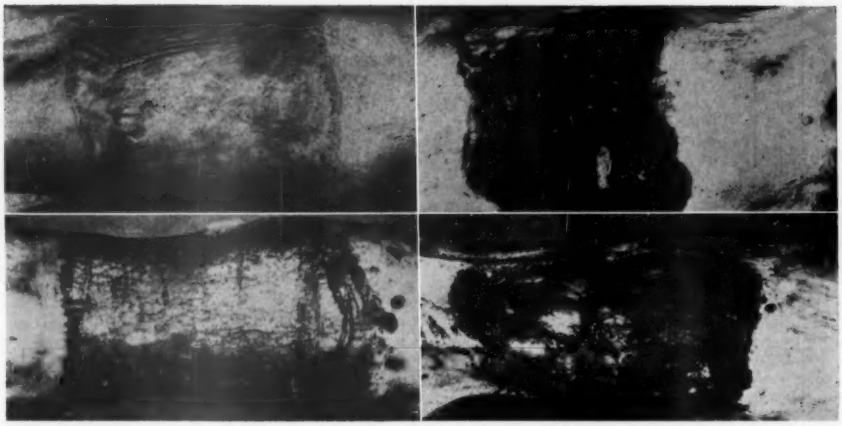

FIG. 1. Comparison of flame and scald burns immediately after injury and days later. On the left are shown the burns of the abdomen within twenty-four hours after injury. The scald (*upper*) shows blanched skin, wrinkled, with minimum edema. The flash (*lower*) shows darkened skin, moderately taut indicating contraction and minimal edema. On the right are shown the burns five to six days after injury. The scald (*upper*) and flash (*lower*) both indicate complete necrosis of all layers of the skin. There is minimal edema of either underlying or adjacent tissue.

to the coccyx, were exposed. These regions totalled 25 per cent body surface area.

When the burns were less extensive, the animals survived from five to fifteen or more days. Thus a critical amount of surface area needs to be exposed to thermal trauma to cause a uniformly high acute mortality within twenty-four to thirty-six hours; animals with less extensive burns invariably survived for many days with no therapy. Although other investigators have had similar experiences, this point has not been sufficiently emphasized. This factor is important because small variations in the degree of trauma due to burns permit untreated animals to survive and thereby make evaluation of treatment hazardous [3].

Although each type of burn represented the minimal thermal trauma needed to produce full-thickness dermal injury, the flash burns appeared to be more superficial than the scalds in our studies and those of Roth, Bales and Pearse [4]. Nevertheless, monkeys subjected to flash burns survived much longer with approximately one-half the surface involvement needed to obtain high early mortality after scalds and succumbed despite fluid therapy.

Fluid Therapy. Therapy was begun from one to two hours after the burn. The amount was approximately that recommended by most investigators, namely, 150 cc. per kg. of body weight, two-thirds of which was given during the first four hours and the remaining one-third twenty hours later (i.e., initially, 4 cc. for each per cent of body surface flash burn per kg. or 2 cc. for each per cent of scald per kg.). The blood or colloid used initially ranged from 1 to 0.5 cc. for each per cent of burn per kg. body weight; these amounts for initial therapy are in between the Evans and the Brooke formulas and similar to that used by Markley et al. [5]. The electrolyte solution utilized was a balanced polyionic solution; combination therapy consisted of one-quarter blood or dextran and three-quarters Ringer's lactate. Intravenous therapy was administered through a PE-50 catheter inserted into a saphenous vein. The volume of fluids administered was sufficient to correct a 40 per cent deficit in blood volume, an 80 per cent deficit in plasma volume, or a 50 per cent loss of extracellular fluid volume.

RESULTS

Comparison of Mortality and Efficacy of Therapy. Figure 2 compares the survival time of untreated monkeys after each type of burn and shows the average results of fluid therapy. When 55 per cent of their body surface area was scalded for fifteen seconds at 75°C., a group of nine untreated monkeys survived for an average of 0.51 days. Eight animals, similarly scalded and treated with whole blood, survived

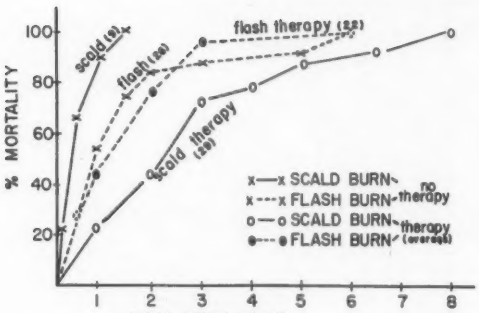

FIG. 2. This figure shows the comparative mortality of scalds and flash burns in monkeys and the effect of fluid therapy in both types of burns. The lines indicating the results of treatment represent the composite average of three formulas utilizing electrolyte solutions alone, or containing one-fourth dextran, or one-fourth whole blood. The results are averaged because there was no significant difference with any form of therapy. The lines indicate the relatively longer survival of untreated animals exposed to flash burn compared to scald injury and the transient prolongation achieved with fluid therapy after scald. The fluid therapy after flash burn failed to achieve any significant prolongation of survival.

3.22 days. Dextran increased survival to 3.14 days in nine animals, while twelve animals treated with electrolyte solution survived 2.40 days. (Considerable variation in survival time occurred; these are average values.) When administered orally, electrolyte solution alone increased survival to 2.50 days in three animals, while half-strength electrolyte solution (0.76 molar) increased survival to 2.42 days in three animals. As reported by other investigators [6,7,8] fluid therapy prolonged survival; the mortality rate after four or five days was not significantly different than that of the controls.

With the flash burn described, quite different results were obtained [9]. The monkeys quickly reacted from the Fluothane anesthesia and were extremely active. The pulse and respirations increased moderately and the temperature fell slightly. The average survival time of the twenty-six untreated monkeys was 1.5 days ± 0.8 day (this is approximately three times the survival time of untreated scalded monkeys). Fluid therapy was tested in twenty-two monkeys, but, as shown in Figure 2, no prolongation of survival time occurred with any of the three fluid regimens. The survival time with all three forms of therapy averaged 1.5 days ± 0.22 day. The detailed comparisons of survival after scalds and flash burns and the results of therapy are shown in Figure 2.

Tissue Electrolyte Changes. Data concerning these changes will be published in detail elsewhere [10] but they can be summarized thus: there is a greater influx of salt and water into the burned skin after scalds than after flash burns. The underlying muscle, however, showed more edema and gain in sodium and loss of potassium after flash than after scald injury. The transient benefit of fluid therapy with prolongation of survival after scald may be attributable to replacement of the fluid and electrolyte acquired by the skin; this does not occur after flash burns.

Blood Chemistry Changes. Detailed studies of these will also be published elsewhere [10] but is is noteworthy that no significant elevation in the plasma potassium, nor decreases in plasma sodium, bicarbonate or protein occurred. There was a slight increase in urea and the volume of urine decreased but was not suppressed until death. There was an elevation of hematocrit in all animals which was lowered by fluid therapy, but raised by whole blood therapy.

CONCLUSIONS AND SUMMARY

A comparison of scald burns and flash burns in monkeys exhibit important differences. Utilizing the minimal trauma for full-thickness dermal injury, a considerably greater surface area must be scalded than exposed to the flash burn to obtain a high mortality rate. In the case of the scald injury the various forms of fluid therapy, electrolyte alone, or with a colloid (dextran), or with whole blood, were equally effective in prolonging survival. Fluid therapy prolonged survival after the scald burn for a few days but this prolongation of survival is not obtained after the flash burn. Somewhat similar results, i.e., slight prolongation of survival after flame burns, were obtained by Walker and Dziemian [11].

The fluid and electrolyte changes in skin and muscle in the two types of burns differ [10]. Therapeutic fluid replacement, sufficient to correct the chemical and compartmental deficits presumed to occur, does not prolong survival after flash burns.

The results of these studies indicate clearly that fluid therapy is supportive rather than specific. For this reason and in view of the remarkably effective homeostatic mechanisms, it would seem important that these not be

impaired by excessive administration of any fluid or combination of fluid, colloid, or blood. Such excessive therapy is entirely possible with the generally recommended formulas. In the 15 to 50 per cent burn group in which survival may be dubious, great restraint is advisable.

We conclude that an effective therapy for the prevention of early mortality after flash burns is not known. For this reason and because flash or flame are frequent causes of burns in man, we are investigating various toxic factors and their antagonists [*12,13*].

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A Different Concept of Volume Replacement in Traumatic Hypovolemia

OBSERVATIONS ON INJURED MAN AND ANIMAL

MORRIS J. FOGELMAN, M.D. AND BEN J. WILSON, M.D., *Dallas, Texas*

From the Department of Surgery, University of Texas, Southwestern Medical School, Dallas, Texas.

THE severely injured patient may suffer from a wide range of physiologic disturbances which result in shock. There can be no universal method for the treatment of shock without clinical assessment of the causative and modifying factors. Hypovolemia represents only one common cause of shock in the injured man, and it should not be considered as the sole cause. This aspect of shock—traumatic hypovolemia—its nature and therapy, is the subject of this report. Our studies were undertaken in order to define and quantitate traumatic hypovolemia in several forms of injury and to derive therapeutic concepts of fluid replacement in trauma based upon clinical and experimental observations.

THE CONCEPT OF TRAUMATIC HYPOVOLEMIA

Reduced circulating blood volume following injury may be due to loss of whole blood, intravascular extracellular fluid or to a combined loss of red cells and extracellular fluid. The losses may have been external or as a result of internal sequestration of blood and body fluids. One of the universal responses to trauma (thermal, contusional, chemical and lacerating) is the formation of edema at the site of injury. Edema fluid characteristically is functionally divorced from plasma and the interstitial fluid in the uninjured part of the body. Net exchanges into and out of an established edema pool are sluggish in rate and small in magnitude; consequently, this depot of fluid electrolytes and variable amounts of serum protein represents a loss, and it is not available to compensate for other losses in vascular or extravascular fluid.

The amount of internal loss of salt water associated with trauma has often defied quantitative description. Loss of extracellular fluid into tissue planes, about fracture sites and areas of contusion, and into major operative sites are inconspicuous when compared to obvious loss of blood. For this reason the loss of fluid is thought not to occur in sufficient quantities to require replacement, yet the majority of all forms of trauma result in combined loss of salt water and blood. A method of measuring loss of salt water in some traumatic states is essential in order to establish whether the amount of loss is great enough to require treatment.

EXPERIMENTS DESIGNED TO QUANTITATE TRAUMATIC LOSS OF FLUID FROM FORMATION OF EDEMA

It is known that radioactive S^{35} is an accurate tool to measure loss of extracellular fluid associated with external loss as with peritoneal dialysis. (Table 1.)

The hypothesis that the reduction in S^{35} volume of distribution actually measured the loss of internal extracellular fluid volume into edematous pools had to be tested for validity. For this purpose, "tourniquet shock" was chosen as a means of inducing shock, which is an established method of producing peripheral vascular collapse by effecting a redistribution of extracellular fluid into the traumatized extremity. The fluid trapped in the leg can be measured approximately by differential volume estimates of the extremity before and after injury. This type of shock can be prevented or

TABLE I
VOLUME MEASUREMENTS IN SALT DEPLETED DOGS

Dog No.*	Weight (kg.)	Extracellular Fluid S^{35} (ml.)	Measured Loss by Dialysate Concentration (ml.)
15A	14.59	3,945	
15B		3,121	
Change		−824	−750
16A	15.4	3,668	
16B		2,719	
Change		−949	−1,045

* A = Normal control animal.
B = Results of volume studies following peritoneal dialysis with 150 ml./kg. of 5 per cent glucose in water and withdrawal one hour after instillation.

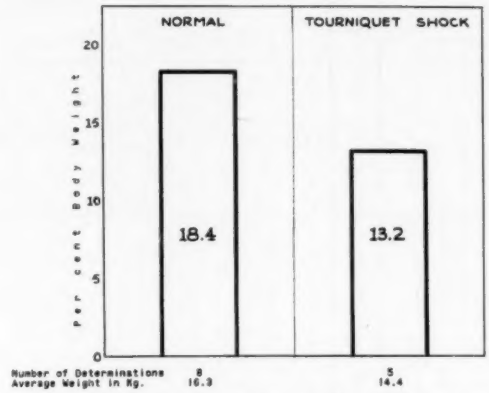

FIG. 1. Functional extracellular fluid-S^{35} volume in normal dogs and dogs receiving tourniquet shock.

adequately treated by the intravenous infusion of salt solutions.

Shock was produced in dogs by the bilateral application of wire tourniquets at the level of the groin after the animal was anesthetized with sodium pentobarbital. Attempts were made to completely exclude the flow of blood to the distal extremity, and in several instances the extremity was beaten with a hammer to produce a crush injury. The tourniquets were allowed to remain in place for periods ranging from one to three hours. Measurements of the size of the extremities were taken before application and after removal of the tourniquets. The results are tabulated in Table II and Figure 1. The change in S^{35} volume of distribu-

TABLE II
TOURNIQUET SHOCK AND EXTRACELLULAR FLUID-S^{35} VOLUME IN DOGS

Dog No.	Weight (kg.)	Determinations*	Blood Pressure (mm. Hg)	Total Volume of Fluid Sequestered into Traumatized Site (L.)	Extracellular Fluid-S^{35} Volume (L.)	S^{35} Volume of Fluid Sequestered into Traumatized Site (L.)
203	10.6	A	148		2.53	
	9.9	B	112	0.686	1.41	1.12
204	13.4	A	130		3.5	
	12.1	B	87	1.696	1.96	1.54
209	17.5	A	147		2.60	
	17.2	B	150	†	2.20	0.40‡
210	19.5	A	150		3.03	
	18.6	B	180	†	2.52	0.51
213	15.5	A	150		2.81	
	14.6	B	140	0.491	2.24	0.57

* A = Control studies.
B = Studies following tourniquet shock.
† = Not measured.
‡ = Approximate average.

TABLE III
EXTRACELLULAR FLUID-S^{35} VOLUME IN NORMAL AND BURNED DOGS

Dog No.	Weight (kg.)	Determinations*	Body Surface Burned† (%)	Plasma Free Hemoglobin‡ (gm.)	Extracellular Fluid-S^{35} Volume		Change in Extracellular Fluid Volume (%)
					Body Weight (%)	L.	
202	13.4	A* (1)			20.2	2.71	
	12.8	A (2)			22.2	2.84	
	11.8	B*	64.0		17.3	2.04	−18.4
215	17.2	A (1)			13.2	2.27	
	13.6	A (2)			17.4	2.37	
	13.6	B	56.2	2.4	12.6	1.72	−17.6
217	14.0	A (1)			15.7	2.20	
	13.6	A (2)			15.7	2.14	
	11.8	B	55.3	1.23	11.5	1.36	−26.7
218	14.5	A (1)			15.7	2.28	
	12.6	A (2)			18.0	2.27	
	12.7	B	49.8	1.67	13.7	1.74	−18.4

* A = Control studies.
B = Studies following burning.
† Animals burned by immersion in water at 85°c. for thirty seconds. Per cent body surface burned determined by measurement.
‡ Maximal values in grams per cent of plasma free hemoglobin which occurred in the animals following burning.

tion in the same animal before and after injury corresponded in proportion to the known changes in the functional volume of extracellular fluid. In addition, the amount of swelling of the leg after the removal of the tourniquet correlated well with the reduction in S^{35} volume. This reduction was directly related to the fall in mean arterial pressure and other evidences of vascular collapse. In the completed experiments, the quantitations of fluid loss by limb measurements generally agreed with the loss as computed by reduction in S^{35} volume of distribution. The average fall in the volume of functional extracellular fluid following the swelling which occurred after removal of the tourniquets was a mass equivalent to 5.2 per cent of the total extracellular fluid volume. This volume of sequestered extracellular fluid is physiologically important. The corollary is that salt solution should be given to effect recovery from this type of injury.

Thermal injury is another form of trauma associated with internal distributional losses of extracellular fluid. The edema which follows external burns is difficult to estimate by the use of external dimensions, therefore, an attempt was made to define the loss of fluid by "burn edema" using the radiosulfate tracer to measure extracellular fluid volume.

Healthy mongrel female dogs were shaved and burned by immersion in a water bath at 85°c. for thirty seconds. Sodium pentobarbital, administered intravenously, was employed for anesthesia. An indwelling catheter was inserted into the bladder before the experiment was started and measurements of mean arterial pressure, plasma free hemoglobin and arterial hematocrit were made. An oral endotracheal tube was inserted to ensure adequacy of the animal's airway during immersion. The extent of burned body surface in each animal was determined by tracing out the burned area with cellophane, determining areas and body weight, and then employing the Cowgill-Drabkin formula for body surface in the dog. The functional volume of extracellular fluid was determined with radioactive S^{35}. An injection of a standard dose was immediately given after burning, and arterial samples were withdrawn at periods extending to two hours.

The results are presented in Table III and

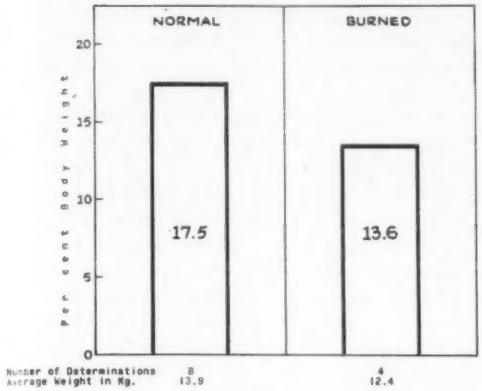

FIG. 2. Functional extracellular fluid-S^{35} volume in normal dogs and in burned dogs.

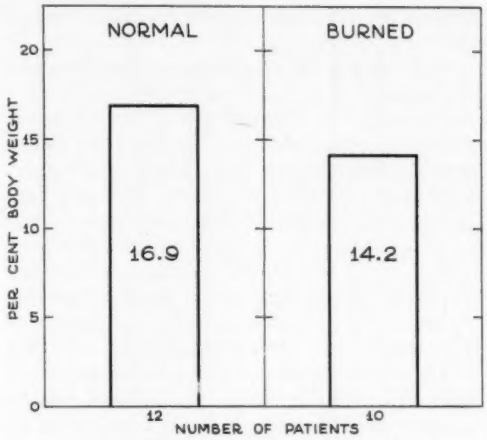

FIG. 3. Functional extracellular fluid-S^{35} volume in normal patients and in burned patients.

Figure 2. Following a standard burn in the dog (55 per cent of body surface) there was an immediate reduction in extracellular fluid. S^{35} volume was approximately equal to 3.9 per cent of the animal's weight or a 25 to 30 per cent reduction occurred in functional extracellular fluid volume. The mean volume of extracellular fluid sequestered in the burned area of the dog approximately one hour after burning was 730 ml. Transposing these changes to man, it can be estimated that following a severe scald (50 per cent body surface) in a man weighing 70 kg., approximately 3 L. of extracellular fluid are lost within one hour.

The radiosulfate space was used in similar fashion to measure extracellular fluid volume in a normal man and in a burned man. (Fig. 3.) The results indicated a significant reduction (p is less than 0.02) in extracellular fluid volume following a severe burn in man. It is well known that large amounts of extracellular fluid are lost into and about an area of burned tissue. These results serve to substantiate the findings in dogs and to confirm our methods for measuring functional salt volume by radiosulfate.

Trauma incident to surgical procedures should, according to our thesis of sequestrational salt water loss in injury, be associated with functional loss of extracellular fluid. Accordingly, radioactive spaces have been measured before and after major operations. Early results revealed that a diminution of functional extracellular fluid occurred during gastrectomy, but the data were not always consistent.

In this surgical laboratory, Shires [1] has recently improved the radiosulfate method and has shown the results to be reproducible within 2 per cent error. The consistent deviations in radiosulfate space after gastric resections and cholecystectomies reveal a mean loss of 2,500 ml. of extracellular fluid volume while a 300 to 900 ml. loss of whole blood occurred.

THE CLINICAL APPLICATION OF THE CONCEPT OF TRAUMATIC HYPOVOLEMIA

The evidence presented herein indicates that measurable amounts of salt water may be lost into sites of injury, and that there is critical need for salt water replacement in trauma. The amount of loss is related to the nature and extent of the injury. In other words, with or without associated loss of blood, the intravenous administration of a salt solution is a necessary adjuvant in the treatment of the hypovolemia which follows injury.

Consideration must be given to the type of injury sustained so that a quantitative assessment of relative needs for replacement of whole blood and salt solution can be made. Hypovolemic states which develop following injury may be divided into three categories based upon the characteristic relative loss of fluid and blood. (1) *Major salt loss:* Burns, peritonitis, multiple contusions and abrasions, extensive cutaneous swellings and abscesses, and intestinal obstruction. (2) *Combined salt and blood loss:* Multiple fractures, major surgical operations, bullet and shotgun wounds, necrotizing infections, and liver, pancreatic and visceral

injury. (3) *Major blood loss:* Primary vascular injury.

The majority of injuries are related to those in categories 1 and 2. Primary vascular injury associated with isolated loss of blood rarely occurs in either soldiers* or civilians. When blood transfusions are given as volume replacement during depletion of extracellular fluid volume, as occurs in the traumatic states listed in category 1, irreversible pulmonary congestion [3] and impaired renal function may result [4]. Whole blood alone given to persons with one of the injuries mentioned in category 2 is an inadequate replacement of fluid volume which does not replenish the physiologic needs for sodium salts. While whole blood is the primary replacement substance for isolated major hemorrhage, an unusual form of trauma, an intravenously administered salt solution may play an important role in recovery from prolonged hemorrhagic shock.

One of the primary objections that has previously been raised to the use of sodium salt solutions in the recently traumatized person is the belief that they have a relative inability to excrete sodium in the urine. The inference has been made that this reflects a state of salt intolerance. That the opposite is true, namely, that the kidney is retaining needed salt and that positive balances of sodium exist as a consequence of internal distributional shifts of sodium, has been demonstrated recently by Drucker et al. [5] and Randall [6]. When sodium was given in sufficient quantities to cover the losses into the areas of injury, the excretion rates of additional sodium loads were normal. Thus, to withhold salt following trauma serves only to intensify the renal insufficiency by failure to replenish plasma volume. This state is attended by reduced renal blood flow and glomerular filtration rates [4].

The ideal salt solution for volume replacement in extracellular fluid deficiency states must contain sodium, and it should approximate the normal ionic composition of interstitial fluid. Special circumstances and associated disease states may indicate the need for alterations in the composition and concentration of the repair solution, but ordinary reductions in volume of extracellular fluid can be treated by the infusion of lactate Ringer's solution. Isotonic sodium chloride is probably not as effective as lactate Ringer's solution because of the dilutional acidosis that may attend the repair of large volume deficits with sodium chloride.

In traumatic shock, as differentiated from hemorrhagic shock, the addition of colloids (plasma protein or dextran) to the saline solution has failed in many controlled experiments to yield higher survival rates than saline solutions alone [7–9]. The failure of colloids to increase survival is in large part probably due to the phenomenon of colloid leakage from the vascular tree, which proceeds in traumatic states associated with capillary injury at rates that are roughly equivalent to those of crystalloid leakage [10]. When a colloid (dextran or plasma protein) is put into a water vehicle without salt and is used as an infusion in traumatic shock, no therapeutic effect can be shown [9,11,12]. In fact, the survival rate is less than with no treatment at all [13].

Unless the condition of the injured patient warrants caution in the production of excessive circulatory blood volume, or if some incidental disease could be optimally managed with a state of mild hypovolemia, the replacement of external or internal loss of fluids and electrolytes should proceed concomitant with loss. When the patient has an injury which is known to be associated with the development of significant reductions of effective extracellular fluid, treatment should be started before oliguria, hypotension and other evidences of vascular collapse occur.

The use of sodium-containing solutions is accepted as an integral part of the treatment of hypovolemia due to direct external loss of sodium-containing secretions. However, the need for salt in the treatment of hemorrhage is not accepted as essential and is generally rejected as unreasonable, ineffective and actually dangerous. The accepted treatment is to infuse whole blood only until decreased vascular volume is restored. Consideration should be given to the fact that loss of blood is attended by shifts of extracellular water and ions into the vascular space. This compensatory movement of interstitial fluid is responsible for the partial restoration of plasma volume which is reflected in the fall of the hemoglobin concentration. Although these facts are basic knowledge, the unappreciated fact is that the gain in the vascular volume represents a loss from the interstices of the cells. A reduction of 1.5 to 2 L.

* Arterial injuries were present in only 1.7 per cent of all soldiers wounded in battle in World War II [2].

of interstitial fluid may accompany hemorrhages of 30 to 50 per cent of blood volume as computed by the fall in the hematocrit. This degree of reduction in the extracellular fluid volume is in itself significant. When not attended by hemorrhage, such losses will provoke symptoms of alteration of cellular activity as manifested by measurable changes in renal function and the function of the central nervous system. When hemorrhage is intermittent, or slow and continuous, the compensatory movement of extracellular fluid into the vascular tree continues, so that each succeeding loss of blood contains relatively more plasma than red cells which increases the amount of fluid loss.

Loss of effective extracellular fluid, in addition to the compensatory loss of interstitial fluid, occurs as a function of time following hemorrhage. McRae [*14*] has shown progressive weight increase in the intestine due to accumulation of fluid in severe shock states. Others have shown that the presence of the intestine in hemorrhagic shock is one factor responsible for the irreversible state of hemorrhage which is not correctable by return of the lost blood [*15*]. This irreversible state is attended by, and can be predicted from, a rise in the hematocrit which indicates additional loss of fluids and electrolytes. One of the likely sites of loss is into the intestine. Recently this hypothesis of fluid loss in hemorrhage has been put to experimental therapeutic test by Stirman [*16*].

Standardized hemorrhagic hypotension was imposed on dogs for two hours, and when the blood that was initially lost was returned, only 20 per cent of the animals survived. If whole blood from a donor was given in addition to the blood which had been lost, the survival rate was unchanged. When lactate Ringer's solution was given (25 per cent of extracellular fluid) to the animal at the end of the shock period and just before returning the blood which had been lost, the number of surviving dogs was tripled. The difference was significant. In summary, the animals' response to the administration of whole blood was modified by the infusion of an electrolyte solution.

Our experiences on the surgical service at Parkland Memorial Hospital lead us to expect restoration of renal function and recovery from hemorrhagic shock without subsequent pulmonary complications, provided that sodium solutions are given prior to the replacement of lost blood when the interval between hemorrhage and treatment is prolonged, or when hemorrhage is persistent or recurrent.

SUMMARY

The hypovolemia which attends severe injury is frequently due to a reduction in the volume of functional extracellular fluid. Data have been presented to quantitate the volume of salt water loss in man and animal following diverse forms of trauma.

Three clinical corollaries were derived from these findings to guide the treatment of hypovolemia incident to trauma: (1) The need for salt replacement must be met in order to effect complete physiologic recovery. (2) Salt replacement should usually be carried out concomitantly with the development of significant losses and before clinical signs of deterioration appear. (3) The administration of a balanced salt solution prior to the replacement of blood in instances of prolonged hemorrhagic shock promotes survival, and it also appears to reduce the pulmonary and renal complications secondary to vascular collapse.

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DISCUSSION OF PAPERS BY DRS. HAYNES; FOX, LASKER AND WINFIELD; AND FOGELMAN AND WILSON

C. P. Artz (Jackson, Miss.): We have again seen various facets of our old problem emphasized. The burn is a surgical wound, with dead tissue. We should attempt to remove the dead tissue, and cover the wound rapidly with skin. There are many technics for this, and we need considerable experimental work with immediate excision and closure four or five days later. Some burned patients can withstand initial excision, others cannot.

How important is early fluid therapy? I think it is interesting that Dr. Fox has brought us this evaluation of fluid therapy in different types of burns, because most past information is based entirely on scald burns. Dr. Blocker and others have pointed out that occasionally burned patients who receive practically no fluid therapy do survive. Several people in this country are using various types of formulas in the treatment of burns, and the results have been about the same. The amount and type of fluid will vary from patient to patient and at present the greatest error is overloading.

I think dextran has its place, but I also think the patient requires treatment with a balanced salt solution. The important thing is not to overexpand the interstitial space.

J. M. Howard (Philadelphia, Pa.): It has again been demonstrated that progress in the treatment of burns lies, and probably will lie, in the gradual recognition that the principles underlying the treatment of thermal burns are identical with or similar to those underlying the treatment of mechanical injuries.

The profession has demonstrated the advantage of excision of dead tissue in mechanical injuries, followed by closure at an early date; it has demonstrated that the loss of fluid in the early hours is predominantly blood in the open wound and that administration of blood is life-saving. Therefore, the principles are early excision of dead tissue, early closure of the wound, and simultaneous replacement of the lost fluid (blood). The trend which is noted here, and which has been pursued in our department in the treatment of thermal burns, is again that the basic principle is to excise the dead tissue with as little trauma as possible; to replace the blood lost *during* operation; and to close the wound as early as possible. It is our observation that the fluids lost into the burn wound are predominantly plasma and extravascular fluid. This, too, must be replaced. As shown in the report presented by Dr. Haynes, this replacement is now being made, and the mortality is low, during the early period when the circulation is so unstable.

F. N. Gurd (Montreal, Can.): I am thoroughly fascinated by Dr. Fogelman's results, and look forward to seeing the data. I am also interested in his thinking on general trauma and in relation to hemorrhagic shock. He spoke of the advisability of adding salt and water to our other therapeutic measures, such as blood, and I wonder if it would not help us all if he would say one word about how much salt should be added to this water. Most salt solutions in common use are high in sodium content. Physiological saline is higher in sodium than the plasma itself, whereas Hartmann's solution contains about 130 mEq. per L.

We tend to forget that badly injured patients are not only losing salt solution through internal shifts and external losses, but are also dehydrating during the period of treatment. Often we neglect to give them enough free water to compensate for the simple dehydration which occurs under operating room lights and through intensified insensible loss.

I would like to ask Dr. Fogelman, therefore, how he would feel about using a somewhat hypotonic salt solution, of say about 100 mEq. of sodium per L., as a general all-purpose solution to supplement blood or plasma in circumstances in which additional salt and water appeared to be indicated.

C. L. Fox (closing): In my opinion, there is really no basis for many of the methods used in the early fluid therapy of the burned patient. Much of the work in animals is suspect, because it has not been sufficiently comprehensive, and I think we ought to re-read some of the papers we quote from so glibly and see how inadequate they are. Today, we would not accept the regimens of fluid therapy on the basis of what has been written.

In Table IV the question of fluid loss in the burn area is covered. (From: Fox, C. L. et al. *Am. J. Surg.*, 89: 731, 1955.) Many estimates of fluid loss have been based on the experience of relatively small burns. We ourselves have been guilty of this in our paper in the *American Journal of Physiology* (151: 155, 1947): one hind leg was burned and fluid loss was measured in the one leg. Many in-

vestigators have utilized tourniquet trauma to indicate fluid shifts without realizing that tourniquet trauma is quite different from burn trauma. In this table the burns were graduated from 7 to 80 per cent body surface area. The edema was always measured in the one hind leg as the total area of burn was increased. The measurements show that the amount of fluid that goes into a burned part is less when the total burn is increased. The maximum edema occurs, paradoxically, in the animal subjected to the smallest burn. Some people have been so rash as to calculate the total loss of fluid in an extensively burned patient on the basis of the analysis of a sample of tissue from a patient with a limited burn of one arm or one small part of the body. This is not correct; until the total loss of fluid in an extensive burn is actually determined, and this has not yet been done, this volume is not known. From the evidence at hand, the loss of fluid in an extensively burned patient is much less than the estimates. Many of our formulas are based on inadequate experience. I think we should not criticize the animals; we should criticize the experiments.

TABLE IV
SODIUM AND WATER SHIFTS WITH INCREASING EXTENT OF BURN

Extent of Burn* Body Surface Area (%)	Hind Leg†		Viscera†	
	Sodium (mEq.)	Water (gm.)	Sodium (mEq.)	Water (gm.)
Mice Received No Fluid Therapy				
None	23	165	23	380
7	59	340	18	330
14	45	285	18	310
60	37	260	20	315
80	33	220	20	315
Mice Received 150 ml./kg. of 0.15 M Sodium Salt Solution‡				
None	23	175	26	385
7	65	445	27	440
14	56	355	23	355
60	45	270	23	365
80	36	225	25	360

* Extent of burn determined by area of body surface immersed. Mice with burns under 60 per cent survive without therapy; designated therapy permits survival of most mice with 60 per cent burn but is ineffective for mice with 80 per cent burn.

† For comparison, analyses of one hind leg tabulated in mEq. Na or gm. H_2O per 100 gm. fat free solids in the leg. Samples taken three hours after burn.

‡ Therapy given intraperitoneally thirty minutes after burn consisted of 0.15 M Na, 0.10 M Cl, 0.05 M HCO_3.

M. J. FOGELMAN (closing): I think we should clearly state the problem in regard to the use of dextran. Is it the vehicle with which dextran is given which is effective or is it dextran combined with the vehicle which promotes apparent good results? In other words, in the treatment of burn shock is dextran in a salt solution more effective than the salt solution alone?

In survival studies in burned dogs relating to various forms of early intravenous therapy, survival was greatest in those animals treated with lactate Ringer's solution alone; dextran in saline was less effective than salt solution alone; and dextran in distilled water solution was less effective than no therapy at all. Results indicate that in the experimental animal lactate Ringer's solution is more effective in the treatment of burns than any other combination of dextran and saline solution. The results of our clinical studies in burned patients treated with lactate Ringer's solution did not substantiate either the need or the superiority for the use of dextran in burns.

Dr. Gurd has considered the volume and the concentration of sodium salts to be given in various forms of traumatic hypovolemia. It is difficult to quantitate the volume needed in multiple injuries. It is empiric, but relatively simple. We know that such a patient has probably lost from 2 to 3 L. of extracellular fluid into the multiple sites of injury and this should be replaced. During the course of a difficult gastric resection or a difficult colectomy as much as 3 L. of salt solution may be sequestered into the peritoneal and operative sites.

The concentration of salt solution to be given should approximate that which is lost, which is a sodium solution isotonic in nature. We see little need to administer a reduced osmolar solution under such conditions. Once salt water volume has been replaced the biologic needs for plain water can be met, slowly and adequately.

The Treatment of Acute Craniocerebral Injuries

W. D. HILST, M.D. AND AAGE NIELSEN, M.D., *Detroit, Michigan*

From the Department of Surgery, Wayne State University College of Medicine, and the Detroit Receiving Hospital, Detroit, Michigan.

MODERN America with its high speed automobile, centralization of population and its inherent turbulence, violence and alcoholism has resulted in an increasing incidence of acute carniocerebral injuries. At Detroit Receiving Hospital this type of injury forms a large segment of the traumatic cases seen in the emergency room. Because of their prevalence, occurrence with other injuries and the significant mortality involved, it is essential that every doctor have a basic knowledge of how to evaluate and treat these patients. For these reasons a review of all patients with craniocerebral injuries admitted to Detroit Receiving Hospital over a two-year period has been undertaken. First, the methods of evaluating, diagnostic studies and clinical care utilized in this period of time and the results obtained are presented. Second, some of the newer adjuncts in treatment being tried will be discussed. Finally, a new classification is given showing the areas in which treatment is satisfactory and others in which it is highly unsatisfactory. Believing this to be of marked clinical importance, we have used the framework of this new classification to discuss some of the individual problems.

MATERIALS AND METHODS

The clinical material for the present study consists of 892 consecutive patients admitted to Detroit Receiving Hospital from January 1, 1957, to December 31, 1958. This includes all head injuries regardless of other injuries which may have been incurred. In order to better evaluate the results, the major criteria used in evaluating these acute craniocerebral injuries must be pointed out.

The major classifications of the level of consciousness used were as follows: (1) no alteration; (2) lethargic, but rational; (3) lethargic or restless, and irrational; and (4) comatose. The important group known as localizing signs were: (1) pupil changes, (2) reflex changes, (3) Babinski's or Hoffmann's sign, (4) localizing seizures, (5) paralysis, and (6) sensory changes. Important signs of increasing intracranial pressure were: (1) decreasing level of consciousness, (2) decreasing pulse and widening pulse pressure, and (3) nausea and vomiting.

The basic routine care of these patients will be outlined and applies to all patients throughout the series. All patients are admitted via the emergency room and are seen initially by the intern and surgery resident on duty. They perform the immediate emergency care needed, such as stopping loss of blood, starting intravenous infusions, splinting fractures and tracheotomy, if needed. The surgical resident then obtains any history available and performs the important initial examination, noting carefully the aforementioned points. Special emphasis must be placed on getting a true level of consciousness for future reference and establishing objective findings whenever possible. He must then carefully evaluate the patient for other injuries. These patients are kept in the emergency room for one to three hours, while roentgenographic and hematologic studies are made and the definitive care of suturing lacerations, casting fractures and giving tetanus antioxin and antibiotics as needed is performed. This period also affords the attending doctor an opportunity to repeatedly evaluate these patients and pick up early changes suggesting the possibility of a developing epidural or subdural hematoma.

These patients are all admitted to general

TABLE I
MODE OF INJURY

Mode	Patients (no.)
Automobile accidents	312
Blunt blow to head	252
Fall and hit head	323
Gunshot wounds of head	5

surgery wards and cared for by the house staff under supervision of the surgical staff. The basic important measures in caring for these patients are as follows: (1) maintenance of a good airway often requiring tracheotomy; (2) limited use of intravenous infusions, keeping the patient on the dry side and preferably using oral or nasogastric tube alimentation; (3) liberal use of oxygen; (4) sedation when needed in only small amounts and consequently at more frequent intervals (luminal administered intramuscularly); (5) no use of narcotics; (6) use of large doses of antibiotics, usually penicillin, streptomycin and sulfadiazine in all compound fractures; (7) elevation of the head of the bed; (8) control of seizures by use of Dilantin® and/or barbiturates administered intravenously; (9) good nursing care with frequent observation of blood pressure, pulse and level of consciousness; and (10) repeated observation of these patients without being in great haste in deciding to operate.

A large majority of these patients progress well and recover under the routine care previously outlined. We have arbitrarily established that all concussions be observed three to four days and skull fractures at least five days even if the patient is asymptomatic. Doing this we found that few patients returned at a later date with complications from their head injury.

RESULTS

In the present series there are 892 patients, or an average of somewhat more than one patient admitted per day. There were 173 females and 719 males. The age ranged from two weeks to eighty-six years, with 278 patients being under twelve years of age. Of the adults, 213 were noted by the admitting doctor to have some degree of alcoholism.

Table I shows the three large groups into which these patients were divided on the basis of mode of injury. We found almost all patients

TABLE II
CLASSIFICATION OF CRANIOCEREBRAL INJURIES

Classification	No.	Deaths	Per cent Mortality	Subdural and Epidural
Cerebral concussion and contusion	431	..	2.3	..
No localizing signs	364	1	.3	1
Localizing signs	67	9	14.0	9
Skull fractures	460	..	15.5	..
No localizing signs:				
Simple	182	9	4.9	3
Compound	121	5	4.1	0
Compound depressed	25	2	8.0	0
Localizing signs:				
Simple	72	37	51.0	24
Compound	40	12	30.0	3
Compound depressed	20	6	31.0	1
Totals	...	81	....	41

fitted well into one of these categories. Despite some basic differences in the mechanism of injury there was no correlation between these and the severity of injury, complications or mortality.

Upon admission a history of unconsciousness was obtained in 78 per cent. In 603 patients this period was less than a half hour. The level of consciousness on initial examination showed the following distribution between the four levels: no alteration, eighty-five patients; lethargic, but rational, 497 patients; lethargic or restless and irrational, 212 patients; and comatose, ninety-seven patients. In addition thirty-three patients had typical lucid intervals. Forty per cent of these had epidural or subdural hematoma.

There were eighty-four deaths in this series of 892 patients, or a mortality rate of 9.4 per cent. Of these forty-one, or 48 per cent, died within twenty-four hours. There were 431 cerebral concussions with a mortality rate of 2.3 per cent, and 456 skull fractures with a mortality rate of 15.5 per cent.

Believing that the foregoing did not adequately pin point the type of craniocerebral injury from which the patient died we reclassified these as shown in Table II. In this table the major divisions of cerebral concussion and skull fractures are followed by a division upon the basis of the appearance of localizing signs. Thus, there were 364 patients with concussions with no localizing signs and one death and sixty-seven patients who showed localizing signs with nine deaths. Skull fractures were similarly divided, but also subdivided into

TABLE III
CONCOMITANT INJURIES

Injury	No.
Fractures	113
Intra-abdominal injuries	6
Eye	6
Pneumothorax	5
Genitourinary	5
Tendon lacerations	4
Maxillofacial lacerations	135

TABLE IV
SURGICAL PROCEDURES FOR CRANIOCEREBRAL INJURIES

Procedure	No.
Débridement of compound fractures	121
Elevation of depressed fractures	38
Trephinations	51
Tracheotomies	86
Lumbar punctures	84
Arteriograms	18

simple, compound or depressed. Thus in the group with no localizing signs there were 182 simple skull fractures with a mortality rate of 4.9 per cent, 121 compound fractures with a rate of 4.1 per cent, and twenty-five depressed fractures with a rate of 8 per cent. In the group showing localizing signs there were seventy-two simple fractures with a mortality rate of 51 per cent, forty compound fractures with a rate of 30 per cent, and twenty depressed fractures with a rate of 31 per cent. We believe the striking difference in the mortality rates noted in the group with localizing signs is very significant and of clinical importance, especially when considering patients for new methods of treatment. Finally, in a separate column we have correlated the occurrence and number of subdural and epidural hematomas found in each of these groups. Certainly there is a good correlation between these and the appearance of localizing signs, but the number falls far short of those that at one time showed these signs or the deaths occurring in these groups. Totaling these figures shows there were forty-one patients with acute subdural hematomas or an over-all incidence of 4.6 per cent. In this group there was a survival rate of 21 per cent. There were forty-five depressed skull fractures, thirty-four of which were compound, with a mortality rate of 18 per cent.

This series once again points out that trauma pays little attention to a single system. Table III shows other major injuries occurring in these patients. Interestingly enough these were believed to be the cause of death in only four patients, or an incidence of less than 1 per cent.

Table IV shows the surgical procedures required as a direct result of craiocerebral injury. There were 121 simple compound fractures requiring débridement and closure. There were forty-five depressed skull fractures requiring elevation and débridement when compounded. Fifty-one trephinations were performed with positive findings in 72 per cent. There were eighty-six tracheotomies performed. In the way of special studies, eighty-four lumbar punctures and eighteen arteriograms were performed. No electroencephalograms were utilized in the acute care of these patients.

COMMENTS

The general method of handling these acute cases and different clinical findings to be watched for has already been outlined. We would now like to consider two important aspects of this series: (1) treatment of the complications that arise in these patients, and (2) cases in which treatment was unsuccessful.

The major things to be diagnosed by the close observation of these patients are those complications which are amenable to surgery, namely, subdural and epidural hematoma. In this series these diagnoses were made on a clinical basis in almost all cases. One must watch closely over a period of hours to days for the appearance of localizing signs, and either a failure of the patient to improve his level of consciousness or a deepening of this level. Reviewing the cases in this group, the most trustworthy sign was that of a persistent unilateral dilated pupil followed by reflex changes and Babinski's sign. The unilateral combination of these was always indicative of a hematoma. One of these signs plus the appearance of localizing seizures, paralysis or sensory loss is suggestive. Ancillary evidence of a decreasing pulse and a widening pulse pressure adds to this diagnosis. Finally, the interpretation of changes in level of consciousness becomes important. A decreasing level must always be weighed as to whether it comes from an expanding mass or brain swelling. In contrast, seldom

is trephination required in the acute stage in a patient showing improvement in his level of consciousness. With an epidural hematoma one has some additional findings, notably: (1) in four of five patients in this series there was a lucid interval, (2) a fracture across the middle meningeal, and (3) a rapid progression of symptoms and findings. In a few patients arteriography has been useful in finally establishing the correct diagnosis. We believe this was indicated in a few patients with no localizing signs and a failure to improve, and those cases requiring differentiation from strokes or subarachnoid hemorrhage. We believe it is not necessary and could be harmful if arteriograms are used in all patients suspected of having subdural hematomas before considering these patients for trephination.

In all cases of suspected subdural or epidural hematoma, trephination, usually with the patient under local anesthesia, was performed with positive findings in 72 per cent. This operation has proved effective in treating the hematoma and is simple to perform with little mortality or morbidity. We have also been impressed that a few patients in whom was found no actual hematoma, but rather an excess of clear fluid, showed improvement postoperatively. Reviewing the autopsies from the entire series there were six unoperated subdural hematomas found. In five of these patients the diagnosis was made antemortem, but no surgery performed because the patient was moribund or had other injuries preventing trephination. Certainly we found no evidence to conclude that anything is to be gained by rushing the patient with absent corneal reflexes or other evidence of severe brain damage to surgery.

The second large group of patients who require early surgery are those with compound depressed fractures. In this group there is no diagnostic problem, and oblique films often aid in determining the amount of depression. Treatment for these patients is one of basic surgical treatment of compound wounds except those involving the basilar structures. The latter require no surgical procedures and should be treated with the general means previously outlined. In general no attempt should be made to obstruct the ear or nasal canal to prevent the drainage of fluid. The simple compound wound should be well débrided, irrigated and closed carefully without drainage. In all patients in this group heavy doses of antibiotics should be used including sulfonamides. The compound depressed fracture requires the same soft tissue care plus usually the removal of the comminuted bone and careful examination of the dura. If the dura has been penetrated, the area below must be carefully searched for bone spicules or fragments and irrigated, and the dura closed. The most frequent and difficult problem in these injuries is control of hemorrhage, especially from a cerebral laceration or a venous sinus which may be opened with the removal of bone fragments. This requires one to have transfusions available and be ready to use coagulation, silver clips and sutures as needed to control the hemorrhage. Finally, in closing the dura, one may need to use a temporal fascia graft because of brain swelling.

The final group of patients requiring early surgery are those with associated surgical injuries. These injuries, involving all systems, require that the surgeon be well versed in the recognition and care of fractures and intra-abdominal, chest and other type injuries.

The figures of an over-all mortality of 9.4 per cent and 15.5. per cent for skull fractures would appear generally quite acceptable. Although when one considers that eighty-four people alone in our series, in a two-year period, died from this type of injury, this becomes impressive as a cause of death. Studying this series we sought to find a particular group of patients wherein these deaths were occurring, thus allowing us to study these patients more thoroughly and aim newer adjuncts in treatent toward them. To be useful this classification must be one that could be made easily and early in these patients' care and not in hindsight. With the classification given previously we believe these criteria were fulfilled. Thus the patients showing localizing signs and marked increase in intracranial pressure accounted for less than 20 per cent of the entire series, but over 80 per cent of the deaths, an over-all mortality rate of 42 per cent. Studying these deaths from the point of view of time of death we thought it significant as an indication of severity of brain damage that 48 per cent were dead in twenty-four hours and 60 per cent in forty-eight hours. This was borne out by autopsy findings of massive brain damage consisting of petechial hemorrhage, especially in the mid-brain and hypothalmus, swelling and edema of the entire brain and in

many cases, herniation. These findings explain well the usual clinical picture seen prior to death of respiratory failure, marked temperature elevation and/or a decreasing level of consciousness. Thus the general treatment previously outlined, which is so effective outside of this group, falls far short here.

Starting from the above findings in the past year we have sought to utilize some further adjuncts in the treatment of individual cases falling in this 42 per cent mortality category. The first of these was the use of intravenous urea. This was utilized in a gram per kilogram dosage and repeated as high as two to three times per day. On only a subjective evaluation this has shown only minimal effectiveness. We are at present setting up a program to use this treatment on alternate patients in this group, and hope to get an objective final evaluation. The next adjunct is that of hypothermia. This has been used in a few patients with severe brain damage, especially when the brain shows rapid swelling after evacuating a subdural or epidural hematoma. It would appear that there has been definite benefit to these patients, but we have encountered great technical difficulties in utilizing this modality. The professional help necessary to maintain a patient at an effective hypothermic level is just not available in a busy general hospital. However, because of the improvement seen in our limited clinical experience and favorable findings in laboratory experiments, it is believed that if one is to save some of these severely injured people it will be with this method. Finally, various artificial breathing mechanisms were used for those patients with respiratory failure, but adequate blood pressure and pulse. So far we have had no cases in which these machines have been successful in keeping the patient alive.

Returning to the entire series a few other findings need to be noted. First of all, in general we found no great benefit to be gained by insisting on early x-ray films of the skull in an injured and often difficult to manage patient. Certainly the clinical findings far supersede any x-ray findings in caring for these patients. Also in this regard we found no good correlation between the type or extent of skull fracture seen on x-ray film and the severity of damage to the brain beneath; the latter of course is the essence of the injury.

We have found patience and persistence to be very important in caring for these patients. Many patients will go hours to days and even weeks before showing improvement, especially as regards level of consciousness. Indeed one child was fully comatose for forty-three days and then made a good recovery. If these patients are to survive one must be careful about watching for intercedent causes which may result in death. The leading among these are: (1) inadequate nutrition; (2) infections, especially of the respiratory and urinary tracts; and (3) decubiti. To avoid these requires good general medical care and the close cooperation and efforts of the doctor and nurse. In regard to preventing decubiti we have found the intermittent air flow mattress to be of great help.

SUMMARY

1. A series of 892 consecutive acute craniocerebral injuries is presented with an over-all mortality rate of 9.4 per cent.

2. The method of handling and treating these injuries, including the surgery involved, is outlined and discussed.

3. A new classification, showing when treatment is quite ineffective, is presented with the view toward letting one select these patients early for additional newer treatment.

4. Some newer adjuncts, notably urea and hypothermia, for care of these patients are discussed.

5. The finding of a lack of correlation between the mode and severity of injury or mortality is noted. This also holds true for the extent, type and position of a skull fracture and amount of brain damage incurred.

Cranial Trephination for Diagnosis and Therapy in Closed Injuries to the Head

A FIVE-YEAR REVIEW

DAVID N. KLUGE, M.D., *Buffalo, New York*

From the Department of Surgery, Neurosurgical Service, Edward J. Meyer Memorial Hospital, Buffalo, New York.

THE importance of trauma as a cause of cerebral disturbances must always be considered in patients with vascular thromboses, alcoholism or mental aberration. The care of such patients when they are comatose or in a state of rapid neurological deterioration often presents a stimulating problem. A complete history may not be available, and a detailed laboratory and radiologic investigation may not be feasible. A complete physical examination including detailed neurological study may fail to suggest a satisfactory explanation. One diagnostic and therapeutic measure of considerable benefit in this situation is exploratory cranial trephination.

The reports of eighty-eight consecutive cases in which diagnostic cranial trephination was performed during a five-year period including the years 1952 through 1956 were carefully examined. An analysis of the indications for this procedure, the clinical and laboratory findings, the surgical or postmortem diagnoses and the follow-up reports are presented to help clarify the problems involved in evaluating such cases. The findings indicate the importance and benefits of exploratory trephination and suggest that the potential hazard of this procedure is minimal in patients who have conditions which are not amenable to surgical therapy.

CLINICAL EXPERIENCE

This institution is a 1,000-bed general hospital, under county administration, and all patients who enter are seen by resident physicians who determine to which department the patients will be admitted.

Trephination was performed on sixty-four males and twenty-four females who ranged in age from seven weeks to seventy-six years. They entered the hospital with a variety of complaints or reasons for admission as shown in Table I. It is noted that three-fourths of these patients were either comatose or delirious at the time of admission.

The diagnoses of the admitting physicians in all the cases are given in Table II. In twenty-six of the eighty-eight cases the diagnosis on admission was subdural hematoma. In most of the other cases an initial diagnosis of alcoholism, brain tumor, cerebral thrombosis or mental disorder was made. Because of the wide range of diagnoses, these patients were sent to various clinical departments in the hospital as listed in Table III.

The preoperative diagnosis was correct in fifty-seven of the eighty-eight cases. Tables IV through VII give the correct diagnoses made at surgery and/or postmortem examination. They

TABLE I
PRINCIPAL REASONS FOR ADMISSION

Symptoms	No. of Patients
Coma	32
Delirium	34
Headache	10
Convulsions	4
Hemiparesis	3
Aphasia	1
Fainting	1
Pulmonary tuberculosis	1
Fever	1
Alcoholism	1

TABLE II
DIAGNOSES ON ADMISSION

Diagnosis	No. of Patients
Subdural hematoma	26
Alcoholism	12
Brain tumor	10
Cerebral thrombosis or hemorrhage	10
Mental disorder	10
Meningitis	7
Cerebral concussion	2
Subacute bacterial endocarditis with cerebral embolism	2
Epistaxis	1
Bronchitis	1
Syphilis of the central nervous system	1
Hypertension	1
Drug overdose	1
Bronchiectasis	1
Pulmonary tuberculosis	1
Heart failure, asthma	1
Fever of unknown origin	1

TABLE III
ORIGINAL HOSPITAL SERVICES TO WHICH PATIENTS WERE ADMITTED

Service	No. of Patients
Medicine	18
Neurosurgery	17
Psychiatry	12
Neurology	11
Alcoholic	10
Pediatric	7
Contagious	7
Surgery	4
Tuberculosis	2

TABLE IV
TRAUMA (FIFTY-FOUR CASES)

Trauma	Cases	Deaths
Acute subdural hematoma	9	3
Bilateral	3	2
With contralateral chronic subdural hematoma	1	..
With contralateral hygroma	3	3
With intracerebral hematoma	6	5
With cerebral laceration and contralateral hygroma	2	2
Bilateral with cerebral laceration	1	1
With epidural hematoma	1	1
With skull fracture and subdural abscess	1	1
Epidural hematoma	1	..
With hygroma	1	1
With bilateral hygroma	1	..
Chronic subdural hematoma	11	3
Bilateral	2	1
With intracerebral hematoma	1	1
Intracerebral hematoma	1	1
Hygroma	1	..
Bilateral	1	..
Bilateral with skull fracture and meningitis	1	1
Cerebral contusion and edema	4	1
Post-traumatic cerebral atrophy	1	..
Post-traumatic epilepsy and hemiparesis	1	..
Total	54	27

are listed as cases of trauma, cerebral vascular lesions, infection and others. Lesions resulting from trauma accounted for the majority of cases (fifty-four), and intracranial hematomas were present in forty-five of these. It should be noted that in fifteen cases of trauma, significant lesions were found bilaterally. There were seven cases of cerebral thrombosis, eight cases involving the complications of meningitis, and four cases of primary brain tumor. The other fifteen lesions encountered provide a diversity of conditions to be considered in managing the patient who is in coma or rapidly approaching such a state of neurological deterioration.

A comparison of the impressions on admission and the final diagnoses in certain categories is given in Table VIII. Of the twelve patients admitted for alcoholism who were subjected to trephination, seven were found to have subdural hematomas and three had hygromas. Similarly, of the ten patients who were initially thought to have cerebral thrombosis, four had subdural hematomas and one had an epidural hematoma. Of the ten patients admitted for mental observation, five patients were found to have subdural hematomas. Of course, a great

TABLE V
CEREBRAL VASCULAR LESIONS (NINE CASES)

Lesion	Cases	Deaths
Thrombosis	7	5
Ruptured cerebral aneurysm	1	1
Hypertensive encephalopathy	1	..
Total	9	6

TABLE VI
INFECTION (FIFTEEN CASES)

Infection	Cases	Deaths
Meningitis with delirium or coma	3	1
Meningitis with communicating hydrocephalus	2	..
Tubercular meningitis with obstructive hydrocephalus	1	..
Subacute bacterial endocarditis with brain abscess	1	..
Tubercular meningitis with cerebral hematoma	1	1
Otitis media with meningeal hydrops	1	..
Viral pneumonia with encephalitis	1	..
Bronchiectasis with brain abscess	1	..
Brain abscess with hydrocephalus	1	1
Subsiding meningitis with hygroma	1	..
Bronchopneumonia	1	1
Brain abscess	1	1
Total	15	5

TABLE VII
OTHERS (TEN CASES)

	Cases	Deaths
Cerebral glioma	4	3
Metastatic carcinoma to the brain	2	2
Cerebral atrophy and dementia	2	..
Drug overdose (Doriden®)	1	..
Idiopathic epilepsy	1	1
Total	10	6

many more patients who did not have cranial injuries were admitted to this hospital for alcoholism, cerebral vascular accidents and mental observation during this period of time. However, Table VIII does indicate the necessity for considering trauma as a cause of the neurological abnormality found in these cases, especially when deterioration occurs.

Evidence of trauma was elicited, either from the history or examination of the head, in fifty-two of the eighty-eight patients in this series. Nine patients were involved in traffic accidents, and nine fell at home. Only thirty-six of the fifty-four patients who had had intracranial trauma had extracranial evidence of head injuries; e.g., abrasions, lacerations or ecchymoses. One or more retinal hemorrhages were found in five patients. No such external evidence of trauma was present in the remaining eighteen. These figures indicate that the absence of obvious scalp injury does not preclude the possibility of serious intracranial injury. This point has been stressed by Gurdjian et al. [2].

TABLE VIII
COMPARISON OF INITIAL AND FINAL DIAGNOSES

Final Diagnoses	Admission Diagnoses		
	Alcoholism (12)	Cerebral Vascular Accident (10)	Mental Observation (10)
Subdural hematoma	7	4	5
Epidural hematoma	..	1	..
Hygroma	3	..	..
Cerebral edema	1	..	..
Brain abscess	..	..	1
Tumor	..	1	2
Cerebral thrombosis	1	4	2
Total	12	10	10

NOTE: Figures in parentheses represent total number of patients in whom diagnosis was made.

The evaluation of various common signs in these cases, such as the level of consciousness, changes in pulse and blood pressure, neurological findings and laboratory studies, has been attempted by correlating them with the final diagnoses.

Twenty-one of the forty-five patients with intracranial hematomas were comatose when admitted to the hospital, fifteen were confused, and nine were oriented. The patients in the last two categories exhibited a fluctuating level of consciousness or became progressively unresponsive during the period of observation before surgery. These patients would frequently exhibit episodes of confusion and lethargy after

TABLE IX
INCREASED INTRACRANIAL PRESSURE
(SIXTY-NINE CASES)

Pulse (change if over 10 beats/min.)	No. of Cases	Blood Pressure (change if over 10 mm. systolic and diastolic)	No. of Cases
Decreased	15	Ascended	11
Same	9	Same	20
Increased	28	Descended	12
Insufficient number of readings preoperatively	17	Insufficient number	26

periods of continued mental improvement. This observation was found to be a most important indication for exploratory trephination when injury to the head was suspected. It follows that the same observer should make frequent repeated visits to such a patient to determine any such fluctuations.

Changes in pulse and blood pressure, as seen in Table IX, gave rather unreliable indications of the increased intracranial pressure which was found in sixty-nine of the cases in this series. These features may be helpful when progressive changes are present, but they are relatively unimportant.

Thirty-eight cases of expanding lesions, which included hematomas on one side only, were reviewed for correlation with so-called "localizing" signs. Dilation of the pupil was present on the same side in fourteen cases, on the opposite side in eight cases, on both sides in two cases, and on neither side in fourteen cases. Papilledema was present in three cases and was seen on the same, on both and on the contralateral side, respectively. Paresis was found to be contralateral in fifteen of the thirty-eight cases, ipsilateral in eleven and absent in five. Seven patients were so deeply unconscious that they could not be adequately tested for paresis. An extensor plantar response (Babinski) was present contralaterally in seven cases, ipsilaterally in four, bilaterally in twenty, and on neither side in seven. Of the thirty-eight patients, thirteen with intracerebral expanding lesions did not exhibit more accurate evidence of localization than those with extracerebral lesions which were expanding.

Lumbar punctures were performed before surgery in sixty-nine of the eighty-eight cases. Of the eighteen specimens which were grossly bloody, two were believed to be due to needle trauma and four were found to contain xanthochromic fluid after centrifuging. The fluid in thirteen cases was xanthochromic, and in thirty-eight cases it was clear. The pressure was recorded in fifty-eight cases and in thirty-six of them it was over 200 mm. water pressure. Total proteins were determined in thirty-two cases by the Looney and Walsh electrophotometric method in which 15 to 45 mg. per cent is considered normal. Seventeen specimens were within this range and fifteen specimens exceeded 45 mg. per cent.

Radiographs of the skull were obtained in forty-one cases, and skull fractures were seen in ten. The fractures were all linear and undisplaced. Most of these films were obtained at the time of admission using the x-ray facilities present in the admission department. Roentgenograms were omitted in some cases, because there was no initial history or evidence of trauma. In other situations the indications for surgery were present at the time of admission, and the risk and delay incurred by roentgenographic examination were believed to outweigh the potential benefit.

Eight pneumoencephalograms were performed preoperatively and were of diagnostic aid. Carotid and vertebral arteriograms were helpful in all eight instances in which they were performed. We have experienced little difficulty with cerebral angiography and have recently been inclined to use this study more frequently. Electroencephalographic evidence was correct and of diagnostic aid in ten of the seventeen cases in which it was obtained.

While it is desirable to obtain as complete a workup as is feasible within the limits of the patient's condition, some of these clinical and laboratory observations show inconsistent patterns especially in localization of a surgically correctable lesion. The fact that the most consistent observation found to support the need for exploratory trephination was the fluctuating level of awareness or the presence of coma in these patients should be emphasized.

All operations were performed in the operating room using either general or local anesthesia. In all cases the scalp was locally infiltrated with procaine containing a small amount of neosynephrine to facilitate analgesia and hemostasis. Bilateral trephination was performed in all but ten cases because bilateral hematomas are frequently encountered. The location of the trephine was in the temporoparietal area in most cases. Six frontal explorations were performed. The burr holes were enlarged in many instances to permit better evacuation of the clots and membranes encountered and to allow for decompression of the brain. Ventricular aspiration and catheter drainage through the trephine was performed in cases of cerebral edema. Trephination alone failed to reveal a lesion and subsequent ventriculographic studies were helpful in arriving at a diagnosis in sixteen cases.

Twenty-six additional procedures were carried out, and there were postoperative complications in twenty-one patients. Infection in

the surgical wound occurred in four instances. Nine patients were re-explored two to fourteen days after surgery, and additional blood clots and subdural membranes were removed. Eight tracheostomies were performed for improved tracheal suction in comatose patients. Four craniotomies were performed in patients found to have brain tumors.

Forty-four patients died, a mortality rate of 50 per cent. Nineteen underwent postmortem examination. The average hospital stay of these forty-four patients before surgery was six days, and postoperatively it was ten days. Twenty-seven deaths were of traumatic origin. This is a 50 per cent mortality rate among patients with traumatic lesions.

In sixteen cases, or 18 per cent of the cases studied, it was found that the lesions encountered were of such a nature that cranial trephination was of no benefit. It served only to rule out a condition such as subdural hematoma in these instances. (Table x.) Of the seven deaths in this group, five occurred in patients who were comatose and in extremis before surgery and one occurred in a delirious patient. It is believed that these deaths were the result of the already existing pathologic condition and were not related to the trephination. The seventh death occurred in a patient with idiopathic epilepsy who was confused when admitted and had grand mal seizures preoperatively. He died four days postoperatively of bronchopneumonia. In this case, it is questionable whether the procedure contributed to the death of the patient. Therefore, the trephinations which were found to be of no benefit were relatively few and of little danger to the patient.

A review of all postmortem examinations performed at this hospital during the period of this study was undertaken to determine how many patients died with an undiscovered cranial condition which was potentially remediable by surgery. It was surprising to find twenty-six such cases including seventeen cases of subdural hematoma, two of brain abscess, and four of neoplasm. Since slightly less than half of those who die in this hospital undergo postmortem examination, it is possible that a considerably larger number of patients who died in this hospital during this five-year period might have benefited from exploratory trephination.

The forty-four patients operated upon and discharged during the course of this study were followed up for two to six years. The average hospital confinement was fifty-one days. The range was from five days to eight and a half months. Twenty-three patients returned to their usual occupations, while eight returned home in an invalid status. Seven others entered institutions with supervised nursing care and six patients were lost to follow up.

TABLE X
NON-SURGICAL CASES

Condition	No. of Patients	No. of Deaths
Post-traumatic cerebral atrophy	1	..
Post-traumatic epilepsy	1	..
Cerebral thrombosis	7	5
Hypertensive encephalopathy	1	..
Viral pneumonia with encephalitis	1	..
Bronchopneumonia	1	1
Cerebral atrophy (unknown etiology)	2	..
Drug overdose	1	..
Idiopathic epilepsy	1	1
Total	16	7

COMMENTS

In patients with fluctuating or progressive confusion and coma, exploratory cranial trephination can be of both diagnostic and therapeutic importance. It may be life saving. This is true in emergency situations in which the patient's deterioration is rapid, and in cases in which the clinical impression is not well substantiated by ancillary studies. It is wise for the *same* physician to evaluate such a case repeatedly during the observation period.

A fluctuating or decreasing level of consciousness with a history or visible evidence of trauma is a most valuable clue. Pupillary size, paresis and plantar reflexes point to neurological abnormalities but are not dependable signs of localization. Spinal fluid studies, specialized radiological studies and electroencephalograms are helpful in questionable cases when treatment is not on an emergency basis. Diagnosis is often exceedingly difficult. In doubtful cases the safest action is to perform exploratory trephination, although in some instances the procedure will prove unrewarding.

The trephination should be bilateral. The evacuation of a hematoma is not necessarily

followed by immediate and complete mental awareness in the patient. Hospitalization may be prolonged and pulmonary complications may require additional procedures. Postoperative bleeding with reaccumulation of a hematoma may occur, especially in alcoholics. This may require re-exploration of the surgical wound.

With such a mortality, the operative risk may be considered high. However, when dealing with patients whose condition is rapidly deteriorating or those in extremis this risk is extenuated because there is a good chance of saving those with such lesions as subdural hematoma. The rate of survival of 50 per cent in this series seems to be a substantial figure.

In twenty-two cases, death was caused by intracerebral trauma, cerebrovascular lesions or tumors. Although surgical intervention did not alter the natural course of events in these cases, it was advisable, even in retrospect. Ten of the eighteen patients with acute subdural hematomas died, in comparison to four of the thirteen patients who had chronic subdural hematoma. This agrees with the higher mortality in patients with acute hematomas found by others [1]. Whether or not earlier surgery could have changed these figures cannot be determined from this study. It depends partly on the severity of the initial injury.

The postoperative studies show that over half of the patients who survived returned to their normal activities and many others to limited domestic activity.

Three important observations are brought out by this study. First, a comparison of the impression on admission and the pathological findings shows that a considerable number of patients who were admitted for alcoholism, cerebral vascular accidents or mental observation had surgically amenable cranial lesions which were frequently of traumatic origin. Second, a review of the routine postmortem diagnoses reveals that many similar cranial lesions were not investigated by exploratory trephination. Third, the number of trephinations performed which were of little or no benefit (therapeutically or in determining the nature of the serious illness involved) were few, indeed.

These observations would strongly suggest that the procedure be used more frequently to avoid overlooking such lesions. It is hoped that more thought will be given to the possibility of head injury without signs of external injury in the future, and that exploratory trephination will be performed on more patients who present the difficult diagnostic problems of coma and delirium.

CONCLUSIONS

1. The indications for and results of cranial trephination in patients who were delirious or comatose have been studied during a five-year period.

2. The difficulty of diagnosis is emphasized by the mixed impression of the preoperative studies.

3. Trephination was beneficial in obtaining a diagnosis and was frequently the only definitive therapy necessary.

4. The lesions encountered were the result of trauma in many cases.

5. The potential hazard of the operation was found to be minimal.

6. A study of postmortem examinations suggests a pressing need for the more frequent use of this procedure.

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Glutamic Oxalacetic Transaminase in the Evaluation of Acute Injury to the Head

S. E. Smith, M.D., *Flint, Michigan*, K. V. Cammack, M.D., *Boise, Idaho*,
M. E. Dodds, M.D. and G. J. Curry, M.D., *Flint, Michigan*

From Hurley Hospital, Flint, Michigan.

Determination of the concentration of various enzymes in body fluids has been found diagnostically useful. One, glutamic oxalacetic transaminase (commonly abbreviated GOT), is normally found in high concentration in the heart, skeletal muscle, spleen, kidney and liver, and elevations in serum levels have been recorded in many diseases, particularly those of the heart and liver.

Elevated levels in the spinal fluid have also been observed. A blood-brain barrier probably exists which prevents most of the GOT from reaching the blood serum in the presence of brain damage. Spinal fluid levels, on the other hand, may be markedly elevated, and abnormal concentrations have been noted in inflammatory, degenerative, vascular and neoplastic diseases of the central nervous system.

This study was planned to investigate the effect of craniocerebral injuries on the GOT concentration in the spinal fluid, and to explore the usefulness of this laboratory procedure in evaluating the extent of brain damage.

An accurate method of measuring the enzyme is available. Briefly, the reaction is as follows:

L-Aspartate + a-Ketoglutaric acid GOT
Oxalacetic acid + Glutamic acid
Oxalacetic acid + DPN H Malic dehydrogenase
Malic acid + DPN

Oxalacetic acid is removed and the GOT reaction forced toward the right. Results are obtained by observing the rate of disappearance of reduced diphosphopyridine nucleotide spectrophotometrically. GOT levels are reported in units per millimeter per minute. Normal spinal fluid levels in man range from 0 to 20 units; serum levels range from 5 to 40 units.

EXPERIMENTAL STUDY

Healthy mongrel dogs from three to four years old were anesthetized with intravenous sodium pentobarbital, and samples of venous blood and cerebrospinal fluid were analyzed to establish control levels of GOT. Craniectomy was performed and measured areas of cerebral cortex were lacerated or bluntly abraded with a guarded scalpel. The depth of injury varied from 1 to 4 mm. while the diameter was constant at 2.5 cm. Craniectomy alone was performed in one animal. Cerebrospinal fluid and serum GOT levels were obtained at hourly intervals until the animals died or were sacrificed. Normal control levels of GOT in the spinal fluid varied from 20 to 40 units, while serum levels ranged from 10 to 20 units. Semi-stupor, spasticity of the forelegs and a tendency to fall to the side of the lesion were indicative of cerebral damage after surgery.

The GOT concentration in the spinal fluid was markedly elevated in all thirteen animals. Within one hour, levels rose as high as 700 units in animals with extensive damage. Figure 1 illustrates the sustained elevation of GOT levels in an animal with an injury 1 mm. deep. Spinal fluid levels remained elevated for seventy-two hours when the animal was sacrificed. Microscopic sections of the brain demonstrated focal cerebral contusion and laceration. In no animal was the serum GOT elevated.

Figure 2 illustrates levels in an animal with cortical lacerations 2.5 cm. in diameter and 4 mm. deep. The rise of GOT was significantly higher and sustained longer in this animal than it was in the animal represented in Figure 1. All animals showed elevations proportionate to the amount of cortical damage.

The control animal had normal GOT con-

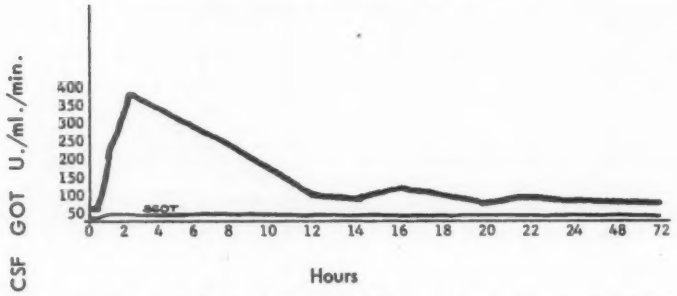

FIG. 1. GOT levels in the cerebrospinal fluid in an animal with 1 mm. depth of injury.

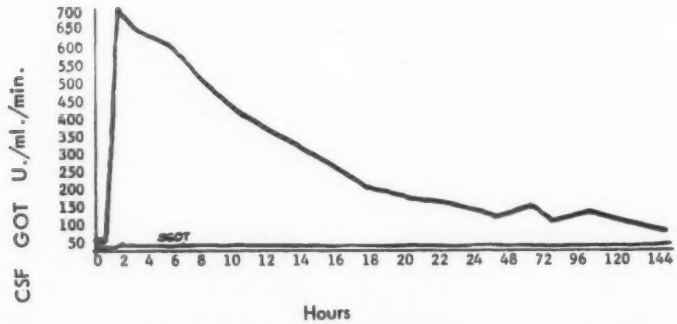

FIG. 2. The extent of GOT rise in the spinal fluid of an animal with 4 mm. depth of brain injury.

centration in both the cerebrospinal fluid and serum.

CLINICAL MATERIAL

Eighty patients with injuries of the cerebrum were studied to determine whether or not GOT levels in the spinal fluid might reflect the severity of the injury. Forty of these patients had a history of head injury and a brief period of unconsciousness without neurologic sequelae, and a diagnosis of cerebral concussion without skull fracture was established. The spinal fluid was free of blood in all cases. Initial and repeated GOT determinations were consistently within normal limits (from 10 to 20 units). One of the forty patients had a mild craniocerebral injury and normal GOT levels in the spinal fluid when he was admitted to the hospital. However, his clinical course was complicated by prolonged convalescence, personality changes and loss of intelligence. Normal GOT levels in the spinal fluid were maintained throughout his hospitalization.

Forty patients had severe craniocerebral injuries manifested by coma, paresis, residual neurologic defects or signs of injury to the brain stem. Contusion or laceration of the cerebrum was the accepted clinical impression. Thirty-eight patients had abnormally high GOT levels in the spinal fluid (up to 160 units). All spinal fluid was immediately centrifuged to remove blood. In twenty-five patients GOT levels in the cerebrospinal fluid ranged from 60 to 85 units. In ten of these, without neurologic sequelae, GOT levels in the spinal fluid were normal within three to four days; however, in fifteen patients, GOT levels remained elevated from seven to ten days, and defects such as marked intellectual impairment, quadriplegia, hemiplegia and paraplegia were apparent. In two patients GOT levels returned to normal with return of consciousness.

Thirteen patients had GOT levels in the spinal fluid ranging from 100 to 160 units. In two of these, it fell to normal within three days. Both patients complained of headache, vertigo, blurring of vision and inability to concentrate. In the other eleven patients, cerebrospinal fluid

FIG. 3. GOT levels in patient described herein.

levels remained elevated from seven to fourteen days and gradually returned to normal. All had severe and persistent neurologic defects.

In two patients with marked neurologic deficiencies, GOT levels were not elevated.

CASE REPORT

A twenty-eight year old white semi-comatose man was admitted to the Emergency Receiving Department following an automobile accident. Pupils were round, regular, bilaterally constricted to 3 mm., and non-reactive to light. A Babinski reflex was present on the right. Lumbar puncture revealed a clear spinal fluid at a pressure of 310 mm. of water. The initial level of GOT was 43 units. (Fig. 3.)

A rise to 160 units occurred during the next three days while decerebrate rigidity was present. No lateralizing signs developed. The GOT level in the spinal fluid gradually decreased over the succeeding three to four weeks. The patient regained consciousness during the twelfth week, although impairment of sensory and motor activity was marked. Quadriplegia persisted with bilateral Babinski reflexes and sluggish pupillary response to light. Electroencephalogram performed during the fourth and tenth week of hospitalization indicated severe generalized cerebral depression, and a pneumoencephalogram showed that the ventricles were of normal size. The patient died of pneumonia

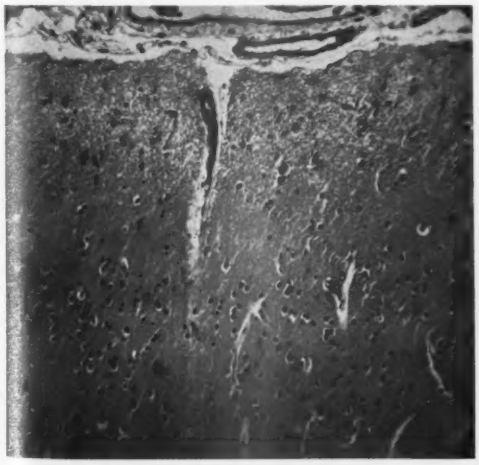

FIG. 4. Sections through the temporal cortex.

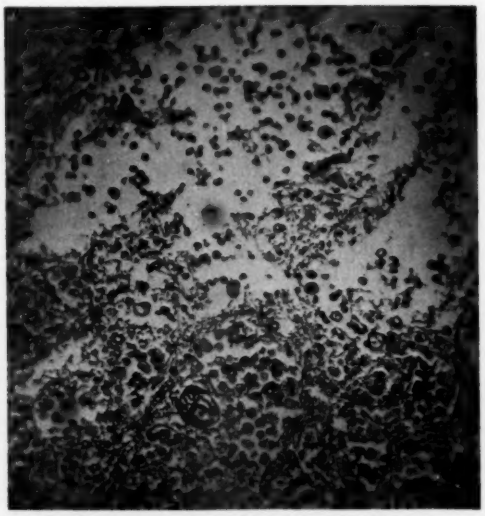

FIG. 5. Sections through the mid-portion of the pons.

FIG. 6. Section through the fourth ventricle.

seventeen weeks after the injury. Microscopic study of sections of the cortex, which were taken from the frontal, parietal, temporal and occipital areas, revealed complete loss of neurons in the outer portions with only a few glial cells remaining. In the deeper portions of the temporal cortices a few atrophic neurons were seen surrounded by glial cells. (Fig. 4.)

Microscopic examination of a section from the mid-portion of the pons showed complete loss of brain substance with replacement by loose reticular fibers containing a few blood vessels and a large number of finely vacuolated macrophages, as well as a few macrophages containing hemosiderin. A moderate number of glial cells were also seen in this section. (Fig. 5.)

Sections taken through the fourth ventricle showed the ependymal surface. In the deeper portions there was an area of necrosis of the nerve fibers with replacement by proliferating glial cells and many macrophages filled with hemosiderin. The infiltration of macrophages and glial cells was particularly marked around the blood vessels. (Fig. 6.)

SUMMARY

Experimentally produced brain injuries resulted in the elevation of GOT levels in the spinal fluid. There was a significant relationship between the severity of the injury and the increased concentration of enzyme in the spinal fluid.

GOT levels in the spinal fluid were normal in thirty-nine of forty patients without clinical evidence of cerebral damage after injury to the head. On the other hand, elevated levels were found in thirty-eight of forty patients with clinical signs of cerebral contusion or laceration.

Patients with persistent and/or high elevations of GOT in the spinal fluid were those with the most extensive brain damage and in whom persistent neurologic defects were predictable.

The concentration of GOT in the spinal fluid is indicative of the severity of a craniocerebral injury and may be helpful in prognosticating end results in the early phases of injury to the head.

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Oblique Motion Studies and Other Non-myelographic Roentgenographic Criteria for Diagnosis of Traumatized or Degenerated Lumbar Intervertebral Discs*

MARTIN S. ABEL, M.D. AND PAUL H. HARMON, M.D., *San Francisco, California*

THIS study correlates the preoperative roentgenographic findings (from plain survey films, motion films and Pantopaque® myelography) with the clinical data, injections of the disc at surgery and pathologic findings at surgery. We hoped to establish precise criteria for the level and extent of operation upon the intervertebral discs, especially in those perplexing cases in which the myelographic data did not adequately reflect the clinical findings.

Patients who had persistent typical or atypical radicular pain and low back pain with negative or inconclusive myelograms are included in the latter category. Cases in which the myelograms do not show either the full extent of the lesion or multilevel lesions are also included. It has been suspected clinically and confirmed by discography with soluble opaque media that two or even three of the lumbar discs often contribute to the patient's symptoms [*9,13,15,18*]. There are also patients who show improvement and even complete disappearance of symptoms when definite protrusions have been shown by myelography [*5,9*]. It is possible that the protrusion may be partially or wholly absorbed and/or fibrosed [*16*].

Thus, the myelogram is inconclusive or misleading in some 20 to 50 per cent of patients [*7,8,9,11*] because it does not reveal all levels of involvement. One authority considers that "a myelogram is an uncertain and unreliable method of demonstrating the presence of a lesion of a lower lumbar disc, and that many such lesions cannot possibly be detected by myelography . . . The procedure is unpleasant for the patient and is cumbersome and time-consuming."

The problem is further complicated by the fact that the disc normally becomes deteriorated and progressively dessicated with advancing age. Many of the roentgenographic criteria apply equally well to the diagnosis of disc degeneration of this type and to more premature disc disease or post-traumatic lesions.

In the process of degeneration and herniation of the nucleus pulposus, much evidence of its passing is demonstrated on the static x-ray film. The first obvious sequella, as substance of the disc is lost, is decrease in the intervertebral space. This is a relatively slow proccess, and it will take six months to several years to detect this after a clearly etiologic traumatic incident or after a definitive surgical excision. The wide range of normal widths and the ease with which an interspace can be made to appear narrowed because of slight angulation of the patient should be considered. The changes are frequently more apparent when the film is taken with the patient in an upright rather than a horizontal position. Moreover, the narrowing is often asymmetric and seen best on the anteroposterior views. The L4 and L5 interspaces are not well visualized unless anteroposterior views are taken with the x-ray beam angled cephalad, or by posteroanterior films with the roentgenographic source at about the geometric center of the arc of the lumbar curve [*13*].

* This study was aided by a research grant from the Kaiser Foundation.

Other criteria for static roentgenograms depend on the direction of protrusion of the disc [13]. If the nucleus herniates up or down into the body of the contiguous vertebra, a Schmorl node or separation of the anterior corner of the vertebra will occur. If the protrusion is directly anterior, the herniation may eventually be well outlined by hypertrophic changes. Posterior herniation may also lead to spurring, although such spurs are more difficult to visualize on lateral and oblique views because of the superimposed bony densities. Sclerotic changes of the contiguous vertebral surfaces also develop with anterior or posterior protrusion. The posterior spurring and sclerotic changes about the lumbosacral joint are best seen on the anteroposterior view with the x-ray beam angled 15 to 20 degrees cephalad.

In the field of motion studies, Hoen and Duncan [6] demonstrated that localized limitation of motion provided a means of diagnosing disc disease in the lower lumbar region. They showed that in a high percentage of patients, films taken in the lateral projection with their spines in flexion and extension showed immobility at the level of the lesion. In the acute, painful stage of the disease this immobility is due to muscle spasm, and movement is reduced by ankylosis as the disc becomes scarred [4].

Tanz [20] and Allbrook [1] have demonstrated increasing immobility in the lower lumbar spine with increasing age. Tanz believes that such immobility is fixed by the time the patient is thirty-five years old. He could find no significant difference in the degree of immobility in patients with and without back pain. However, in a much larger series of cases, Mensor, Gross and Duval [17] found a significantly higher percentage of immobility in patients who had low back pain—100 per cent in those with intervertebral disc syndrome.

Of somewhat greater specificity are evidences of instability on motion studies. These include abnormal widening and narrowing anteriorly and/or posteriorly in extension and flexion and abnormal motions such as pseudospondylolisthesis. Knutsson [14] demonstrated the great importance of sliding motions of the two vertebrae with respect to one another. This is quite specific for disc degeneration, but it requires rather exact positioning of the patient so that exact superimposition of the extension and flexion will be demonstrated on films for comparison. He also points out the existence of the vacuum phenomena which can be seen on hyperextension and demonstrates the actual location of early deterioration of a disc. This has rarely been demonstrated in our experience. It was our feeling that further investigation of motion studies was indicated for additional roentgenographic criteria.

CLINICAL AND EXPERIMENTAL DATA

Our study includes 347 patients, with and without back symptoms, and twenty-two asymptomatic control subjects (internes and residents). The lateral films were taken with the patient erect, without shoes, in hyperextension and flexion of the back. The patients were told to bend with a rolling motion extending from the thorax down. This movement was designed to flex the entire spine physiologically before rotation of the pelvis. The pelvis was allowed to rotate during the latter part of flexion because, in our experience, the final bit of flexion of the lower lumbar spine may accompany such rotation. For this reason no fixation band was used about the pelvis.

The subjects in the control group were twenty-eight to thirty-eight years of age. The amount of motion at each level was measured and recorded. Average motion at each level was measured but the figures are of little value, because (as noted in other series [1,20]) there is a tremendously wide range in the degree of motion at all levels. In this series, there were three subjects with no motion at the L_5 level and one with no motion at L_5 or L_4. Another group of twenty patients over forty years of age with no history of back complaints served as a control for our older age groups.

The 347 patients were divided into groups according to symptoms and surgery: 114 patients had proved disc disease at surgery, seventy-seven patients had low back complaints but had not yet come to surgery, and 156 patients were asymptomatic. This last group served as an additional control group.

These groups were divided into those above and below forty years of age, and immobility at the lower lumbar levels was tabulated. (Fig. 1.) The patients were also divided according to sex, but this showed no significant prevalence in either sex.

There is an obvious and significant difference between the younger and older age groups in the asymptomatic group. This difference does not prevail in the group of patients who had surgical

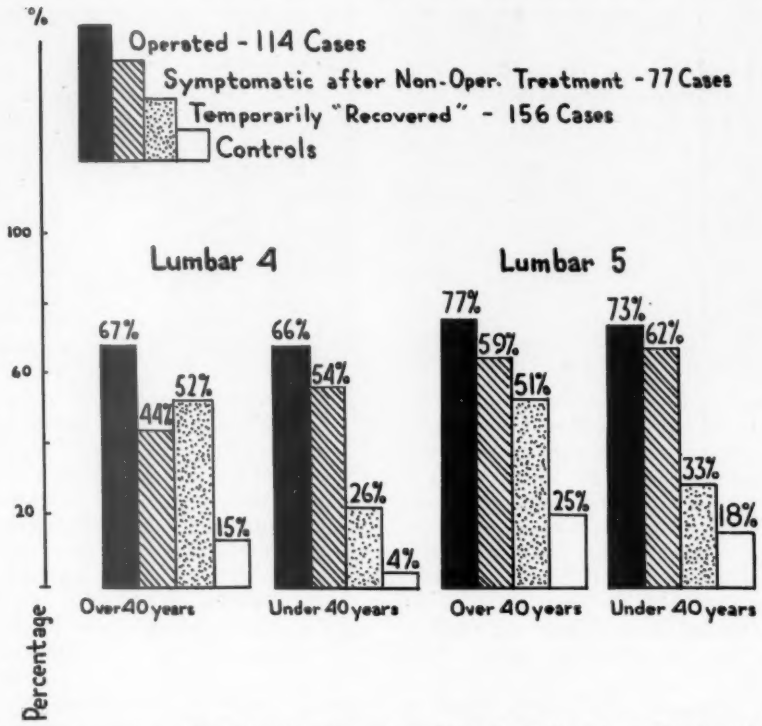


FIG. 1. Comparison of limitation of motion on lateral "bending" films of 347 patients with low back complaints and forty-two controls (twenty-two under the age of forty). There is an obvious and striking decrease in mobility in patients with surgically proved disc disease as compared with the control series. The groups of patients not operated upon are probably heterogeneous and contain patients with and without disc lesions. There is a significant decrease in mobility in the older group of control patients, but there is no such significant difference dependent on age in the patients with proved disc disease.

intervention and proved disc disease, and there is a sharp and significant increase in immobility in all of this group.

The data for the group which did not come to surgery is between the control and operative groups. This undoubtedly indicates that this is a less homogeneous group, and it includes both patients with and without disc disease.

Free motion throughout the lumbar spine is conversely correlated with the absence of disc disease. Only 10 per cent of the patients who underwent surgery and had proved lesions of the disc had completely free motion on the lateral films in which the back was flexed and extended as compared to 80 per cent of the control group. Forty per cent of the patients in the asymptomatic group had motion throughout, compared to only 33 per cent of the patients in the symptomatic group.

The results certainly indicate that disc disease is a cause for localized immobility of the lower lumbar spine, although the immobility is by no means pathognomonic and may be caused by other factors, notably aging. This would indicate the advisability of correlating this sign with other criteria.

More specifically significant evidence of disc disease is the demonstration of instability—sliding motions, hypermobility, pseudospondylolisthesis, etc.—at the level of suspected disc disease. This was noted much less frequently on our films which were taken when the patient's spine was flexed and extended. This is partially due to the difficulty in seeing small displacements on film unless extreme care has been used in positioning the patient.

It is undoubtedly true that instability is common, but it is difficult to demonstrate and

is frequently masked by the muscle spasm. In a group of twenty-five patients with disc lesions proved surgically, films taken with the spine flexed showed immobility at one or more levels in twenty-four. These patients were given paravertebral blocs with Novocain® before films of the same type were repeated. Motion was then demonstrated at one or more of the previously immobilized levels of the spine in ten patients. Abnormal motion indicative of instability was then demonstrated at single levels in three of these patients.

"BENDING" STUDIES WITH OBLIQUE VIEWS

It has been pointed out by Steindler [*19*] that the nucleus pulposus of the normal intervertebral disc serves as the fulcrum of motion between the vertebrae. There is a concurrent gliding motion of the facets which serves to channel the motion. It has been shown by Gianturco [*10*] that in the presence of disc disease the fulcrum of motion shifts markedly, in flexion and extension. This shift is usually posterior and toward the facet area. If the fulcrum of motion is at or near the facet, it follows that the normal gliding motion would not occur. Also, if the fulcrum were shifted far anteriorly, motion at the facets would be grossly abnormal.

In order to study facet motion further, the lumbar spine was removed from a recently deceased patient, and roentgenograms were taken with the spine in extension and flexion in the lateral and both oblique projections. The facet motion could be seen quite well on the oblique views, and the amount of motion was measured at each level by measuring the vertical distance between the superior and inferior tips of the articulating facets, respectively. There was motion at all levels, and the measurements were apparently not affected significantly by minor changes in the obliqueness of the spine. The facet surfaces were substantially parallel at all levels on both sides.

The third and fourth intervertebral spaces were then incised anteriorly and on the left only. Much of the left half of the disc at L3 was rongeured out. The disc at L4 was incised deeply but not much of the disc was removed. The lateral and oblique films were then repeated.

On the oblique views on the altered left side there was then no normal gliding motion at the facets of L3 or L4 and no change in the distance between the tips of the articulating facets between flexion and extension. However, asymmetric widening of the apophyseal joints was noted on extension at both levels. Figure 2 shows films and diagrams of the motion on the affected side before and after altering the discs. The motion on the unaltered right side was not affected. On the lateral views, after the disc incisions, there was excessive mobility on extension.

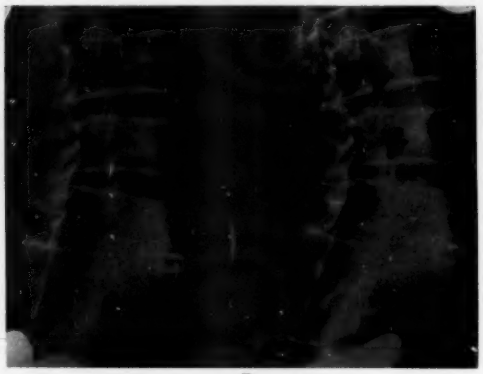
It is clear that after alteration of the discs at L3 and L4, the spine at these levels became unstable on the left side alone, and that the fulcrum of motion shifted posteriorly to some point near the facets. Thus, instead of a normal gliding motion of the facets there was only a "rocking" motion. It was rather interesting to note that the facet motion was equally abnormal at both levels, despite the fact that more of the disc at L3 was removed.

A technic for similar oblique roentgenograms of patients' spines was devised as follows: First, if there was any element of muscle spasm (as there was in most of our patients), the patient received a paravertebral block on the affected side or sides. The patient stands before the upright Bucky machine in an oblique position, 60 degrees off the anteroposterior position, and bends straight forward and backward for the exposures. He leans against the Bucky support when he bends backward, and he supports himself on the back of a chair in the reverse position. The roentgen beam is directed to the lower lumbar spine at an angle of 10 degrees cephalad. Both oblique and lateral films are taken in these positions.

Thirty-five patients were examined by this technic and twenty-five of them came to surgery. The criteria for diagnosis of disc degeneration was demonstration of lack of gliding motion at a localized level or levels, particularly when it was accompanied by evidence of a "rocking" motion, as indicated by asymmetric widening of the apophyseal joint. The immobility alone—lack of gliding motion as evidenced by a constant distance between the tips of the apposing facets—was considered conclusive if motion was seen at the affected level between the vertebral bodies on lateral and/or oblique roentgenograms. "Rocking" motion was also considered abnormal if limited to one side and even if accompanied by some gliding. (Figs. 3 and 4).

In the twenty-five patients who came to

2A



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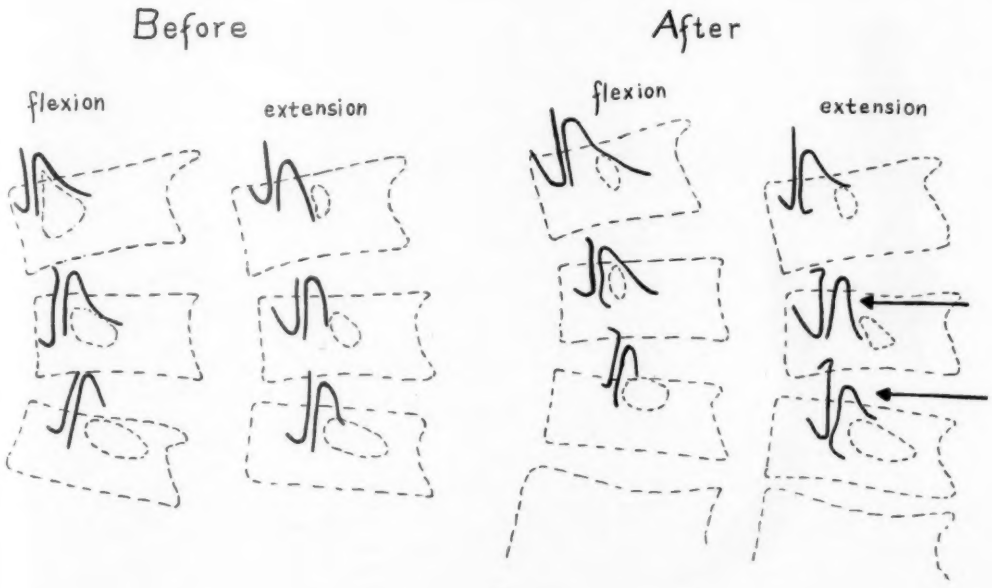
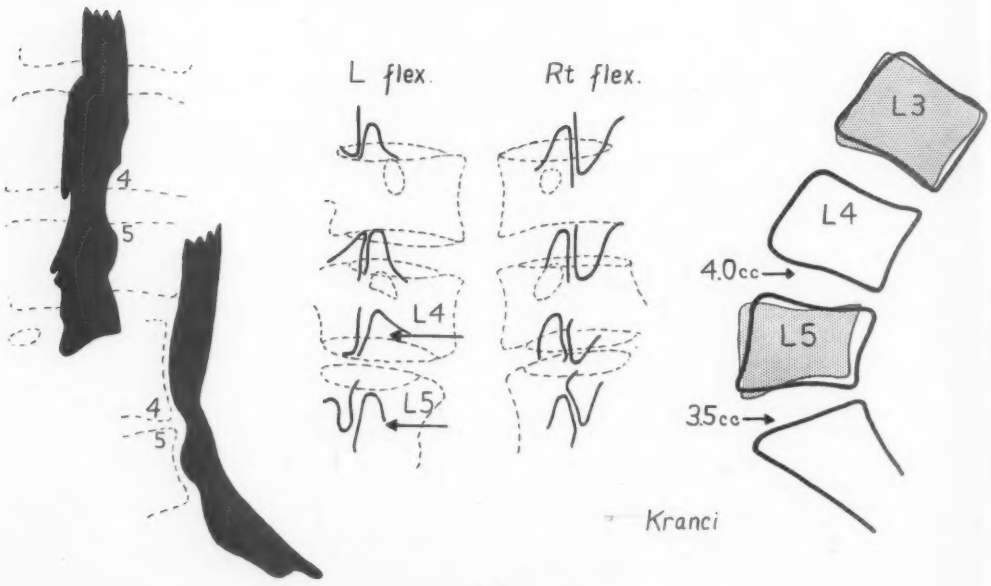


2C

FIG. 2. Cadaver specimen studies. A, oblique projections showing the left apophyseal joints. On extension and flexion there is limited but normal gliding motion of the facets at all levels seen. B, oblique projections showing the left apophyseal joints after incision of the discs at L3 and L4 on the left side and partial removal of the left half of the disc at L3. There is now no normal gliding motion at the levels of L3 and L4, only an irregular widening of the joints, especially on extension, about the same at both levels. The facet motion on the right side remained normal after the left-sided disc excisions. C, diagrammatic tracings of the roentgenograms in (A) and (B). The abnormal "rocking" motion seen after the disc incisions is evidence of instability and is quite a specific sign of disc disease.

surgery, thirty-five diseased discs were found. All the lower lumbar discs were tested by injection of saline during surgery. Thirty-four of the thirty-five discs believed to be abnormal proved to be diseased when the injection test was used and at the time of surgical exploration, and one was considered to be in a borderline condition. By this method, 81 per cent of the pathologic discs found surgically were diagnosed preoperatively.

3A



3B

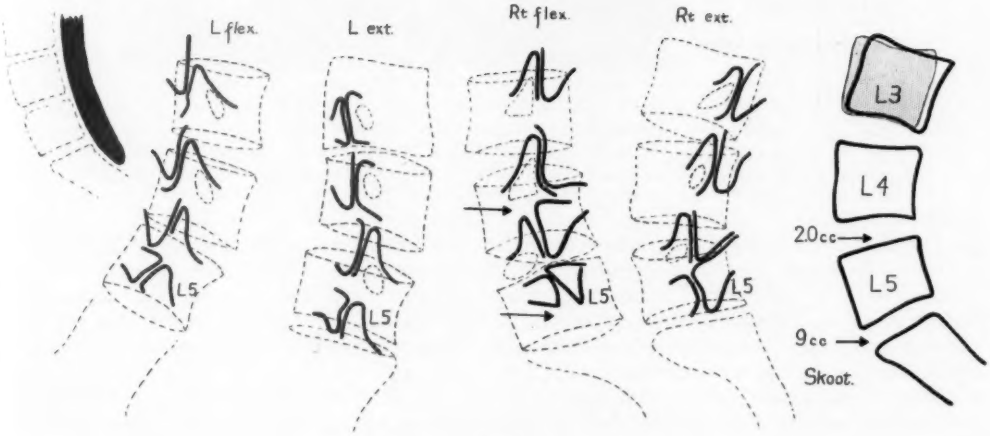
FIG. 3. This forty year old woman complained of severe backache and had no reflex or sensory changes and no response to bedrest or other conservative measures. A, oblique motion studies, left side. There is abnormal "rocking" motion at both L4 and L5. Diagnosis was disc disease at both levels. B, diagrammatic tracing of oblique and lateral "bending" studies and myelogram. Myelography disclosed a large defect at L4 and a less definite defect at L5. On lateral "bending" studies there was immobility at L4 but fair motion at L5. At surgery both discs were abnormal and admitted, respectively, 4 cc. and 3.5 cc. of saline on injection.

CORRELATION OF ALL PREOPERATIVE ROENTGENOGRAPHIC CRITERIA WITH SURGICAL FINDINGS

In Figure 5, the comparative data obtained from lateral "bending" studies, oblique "bending" studies, myelography and other roentgenographic criteria are correlated with the injection data at surgery and the operative findings.

Positive findings on myelograms proved to be an accurate diagnostic procedure when

4A



4B

FIG. 4. This forty-six year old woman complained of a variable amount of backache with alternating right and left sciatica of many years' duration, relieved by bedrest. A, oblique motion studies, right side. There is a loss of normal gliding motion at both L4 and L5 with abnormal "rocking" at both levels. Diagnosis was disease of the discs at L4 and L5. B, diagrammatic tracings of oblique and lateral "bending" studies. In comparison with the abnormal motion on the right, seen in (A), motion on the left was normal. There was immobility at both levels on the lateral studies. At surgery, both discs at L4 and L5 were abnormal and admitted, respectively, 20 cc. and 9 cc. of saline on injection.

positive (94 per cent). However, the total number of myelograms were diagnostic in only 52 per cent of the diseased discs found at surgery.

The oblique roentgenographic studies alone demonstrated 81 per cent of the diseased discs, and the lateral "bending" films were positive in 76 per cent. The rate of diagnostic accuracy was 96 per cent when these two types of films were used. When these data were combined with other roentgenographic criteria, the rate increased to 98 per cent.

COMMENTS

In general, the roentgenographic criteria for discogenic disease fall into four categories according to pathogenesis:

Alteration in the volume and configuration of the disc is indicated by narrowing of the interspace which is often localized anteriorly, posteriorly or unilaterally according to the site of the degeneration or protrusion. A second indication is defects seen on myelograms.

When there is a *long term reactive response to*

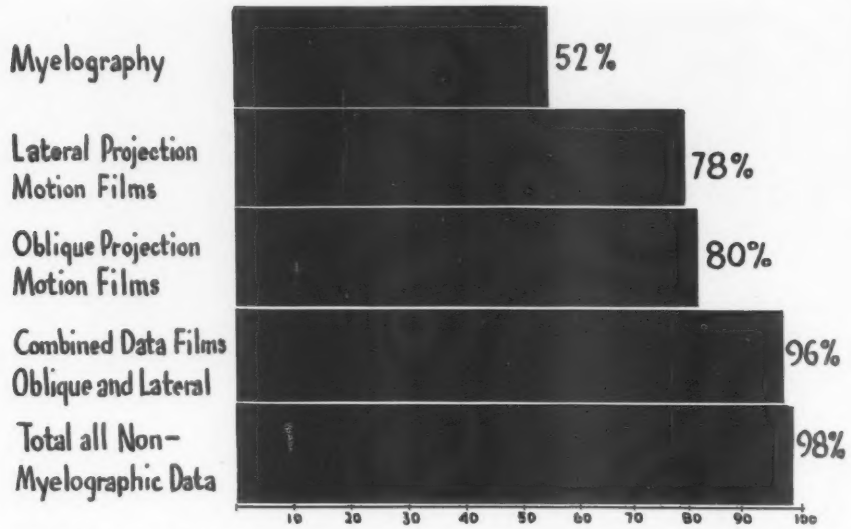


FIG. 5. Comparison of diagnostic correlation of various studies of forty-five surgically proved diseased discs in twenty-five patients (saline injection of disc = 100 per cent). This group includes all the surgically proved cases with oblique motion studies. The percentages hold true for larger series of myelograms and lateral motion studies. The fact that the best diagnostic results were obtained by combining and correlating the results of diverse studies should be emphasized.

an altered disc, roentgenograms show marginal sclerosis, spurring, and/or Schmorl's nodes with surrounding sclerosis. The spurring is a much more specific diagnostic factor posteriorly than anteriorly, and should be seen at the level of L_4 and L_5 on the anteroposterior film in which the x-ray beam is angled cephalad.

Localized immobility seen at the level of the lesion on lateral anteroposterior "bending" films is due to *reaction to pain.*

Altered mechanics and loss of stability at the affected level will be evident when facet motion is abnormal on oblique "bending" films. There is a loss of normal gliding motion and/or an abnormal "rocker" motion which is the consequence of loss of disc turgor and a shift of the normal fulcrum of motion posteriorly. A second factor is alteration of mobility seen on lateral "bending" films. There may be excessive mobility, sliding motions, rotatory motion and pseudospondylolisthesis or reverse spondylolisthesis.

Of these criteria, defects seen on myelograms are specific and significant in abnormal placement of the disc. This abnormality may and very frequenty does cause symptoms.

Other criteria in the first two categories are the findings which indicate altered static anatomy. Even when unequivocally the result of disc disease, these changes may be completely compensated, and may not produce subjective symptoms. Indeed, the spurring and sclerotic changes are *ipso facto* stabilizing processes.

In the third category, the immobilization is a response to pain when it is caused by disc disease, and it is obviously an important symptom. The finding, unfortunately, becomes somewhat non-specific in a high percentage of such immobilization problems when it is not caused by response to discogenic pain. On the other hand, we have found that free motion on the lateral "bending" film is an indication of freedom from discogenic disease.

The findings in the fourth category are all indicative of instability, and they are thus quite specific for disc disease [*14*]. Therefore, it is not surprising that these criteria have, in our experience, afforded the best correlation with symptomatology.

Abnormal stress and strain on the apophyseal joints causes "rocking" motions. Our attention has been especially directed to this as a potential cause of local pain and incompletely referred sciatic pain. In the past, a number of authors [*3,12*] have attributed some of the pain

6A 6B

FIG. 6. This thirty-eight year old woman had persistent low back pain and muscle spasm six months after surgery for anterior interbody fusion of L4 and L5. Roentgenograms showed good fusion at L5, but some instability at L4 with kyphus and a "rocking" motion on the facets at L4. Symptoms were relieved temporarily by posterior paraspinous injection of Cyclaine.® A, lateral view shows kyphus at L4, worse on standing, with the abnormal widening of the apophyseal joints at L4 inferiorly. B, the oblique view shows the irregular widening of the apophyseal joint at L4 with evidence of early osteoarthritic change. The presenting symptoms were relieved immediately after resection of the facet of L4 and posterior bone grafting.

of disc disease to secondary apophyseal joint subluxations and traumatic arthritis. Positive proof of the etiology of the pain is lacking, but the involvement of the apophyseal joints is easily and often demonstrated. Ayres [3] found apophyseal joint arthritis at the level of the disc lesion in preoperative roentgenograms of 17 per cent of his patients.

We have treated two patients in whom unusually persistent localized back pain developed (with incomplete sciatic radiation) after surgical fusion of the anterior vertebral bodies. They had been completely relieved of their preoperative complaints, and the localized back pain was a new symptom. Asymmetric widening of the apophyseal joints had developed postoperatively at the level of the fusion in both patients.

In one case, we believed that the abnormal facet fusion was interfering with good approximation and complete fusion of the bodies. (Fig. 6.) The pain was relieved by paraspinal block. A secondary operation was performed, and traumatic arthritis was found in the apophyseal joints at the affected level. The facets were resected, and a posterior fusion was done. This resulted in immediate and complete relief of the preoperative back pain and muscle spasm. We believe that the matter of facet pain warrants further consideration and investigation.

CONCLUSIONS

We have described some new criteria to aid in the diagnosis of disc disease by the use of oblique "bending" films. These findings indicate instability at the level of the diseased disc where the fulcrum of motion is shifted posteriorly from the nucleus pulposus toward the region of the apophyseal joints. We have found that roentgenograms taken with the spine flexed and extended, in both the oblique projection and the lateral projection, are superior to myelography in the complete preoperative evaluation of our patients. Almost all the diseased discs in our series could be adequately localized preoperatively when we used all of the available non-myelographic roentgenographic criteria.

We should like to emphasize the importance of correlating all roentgenographic criteria (myelographic and non-myelographic) and not depending on a single procedure. Demonstration of a myelographic defect and abnormalities on the oblique "bending" films and other evidences of instability are the only specific indications of disease of the intervertebral discs.

Acknowledgement: We are grateful to the Department of Roentgenology, Kaiser Foundation Hospital, for the myelographic studies and the majority of the lateral projection bending films; and to Dorothy R. Harmon for the tracings and sketches of the roentgenograms.

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DISCUSSION OF PAPERS BY DRS. HILST AND NIELSEN; KLUGE; SMITH, CAMMACK, DODDS AND CURRY; AND ABEL AND HARMON

Elisha S. Gurdjian (Detroit, Mich.): The paper by Drs. Hilst and Nielsen was very interesting. I would like to ask a question about the prognostic value of the state of consciousness in the patient with an injury to the head. Those who remain unconscious for several hours or longer have a much higher mortality than those who become conscious in a short period of time. I did wonder what the authors' percentages were in this connection. In a previous series of ours, which in many instances coincided with the findings of Drs. Hilst and Nielsen from the Receiving Hospital, we found a 40 per cent mortality among those who remained unconscious for long periods of time.

When there are large series of cases of injuries to the head, as at the Receiving Hospital, some of the newer technics such as hypothermia should be utilized, to see whether or not they are of value and to what extent.

Dr. Kluge stated well that in the unconscious patient, even though trauma may not be suspected, one should look for the possibilities of its results. Whether one uses trephination or preoperative diagnostic studies is of little concern. We would prefer preoperative studies, arteriography or air studies prior to the trephination. On the other hand, if trephination for diagnostic purposes turns out to be negative, I assume that the author would go ahead with his diagnostic studies to see whether or not there is a deep-seated lesion in the cranial cavity.

Regarding the paper of Dr. Smith and his associates, there are three questions I would like to ask. We know that in the presence of extensive contusions of the body, with involvement of the liver, spleen and other organs, there is a definite increase in the transaminase of the serum. My first question is when there is an injury to the head with an associated injury to the body, what about the situation in which there is bloody cerebrospinal fluid with interruption of the blood brain barrier? Some of the transaminase from the serum side can enter the spinal fluid. Are such patients apt to show

high levels of transaminase in spite of the fact that the nervous system may not be injured seriously?

The second question I would like to ask is, can we make this test simpler? Instead of having three spinal punctures per day for ten days, can we utilize the results from two or three punctures? I think many in our services do two or three punctures in ten days in certain patients with injury to the head. Possibly the transaminase studies on such specimens might be worth while. I would like to know the authors' thoughts on this. I certainly hope they will continue with this study so as to make this test, as well as tests on lactic acid dehydrogenase (which also parallel transaminase changes), more simple clinically.

My third question concerns the patient who is very seriously ill with little or no contusions but with punctate hemorrhages, or less than that, in the brain stem. What would it show on transaminase studies?

PAUL H. HARMON (San Francisco, Calif.): It is the opinion of our group that results from the surgical treatment of the lumbar disc-vertebral disorders can be improved and the treatment base broadened by (1) a positive diagnosis for persons with symptomatic discs whose myelographic and neurologic diagnoses are inconclusive; and (2) efforts to define and deal with more multilevel pathology, thereby lowering the percentage of poor and fair results, and lowering the incidence of spinal instability and recurring radicular pains after excisional operations. Most reports minimize the two latter factors, and there is no reliable data on results of attempts to broaden the basis for surgical treatment. Simple disc excision has a definite but also limited field of usefulness for the typical easily recognized unilevel lower lumbar disc syndrome. Spinal stabilization is required for the best results in atypical cases and in most persons beyond the age of forty-five years.

Dr. Abel's paper deals chiefly with the diagnostic phases. However, diagnosis cannot be separated from treatment. Broadening the base of diagnosis is a step toward increasing the number of persons benefiting from definitive treatment of lumbar disc problems. While the greater majority of persons obtain satisfactory results from non-operative methods of treatment, there are many who are not benefited, and disc excision and spinal stabilization must then be performed.

Dr. Abel's paper not only deals with *who* should be operated upon but also points out the groups likely to get well without operative intervention (those who retain spinal motion on motion studies). His studies are most important for localization of the lesion or lesions in cases in which myelography has failed. Motion studies make myelographic investigation unnecessary if confirmatory discography or disc injection is done at surgery.

The decision to perform the surgical procedure is usually made by the failure of conservative methods, and not by finding alterations in the form and function of the lumbar vertebrae by the methods outlined in Dr. Abel's paper. While these changes are also found in asymptomatic persons, the failure of motion and of demonstrated spinal instability plus static roentgenographic alterations are just as often localizing in symptomatic persons. The precise difference and the real underlying production of symptoms is not understood. While past practices tend toward a single-level diagnosis by myelography and/or discography, the studies of Dr. Abel and others point to both the most caudal levels of defective and symptomatic lumbar spine discs in many but not all persons with radicular pain in the lower leg.

There is no agreement on the number of persons having unsatisfactory results from conventional disc excisional operations. As orthopedic surgeons, we see more than our share. A safe estimate is about 15 to 20 per cent, including persons who have "recurrences" after several months, usually due to symptoms at another level. For those persons who (1) are more than forty-five or fifty years of age, (2) are in occupations requiring strenuous use of the spine, (3) have roentgenographic evidence of disordered discs at several levels by one or more of the methods outlined by Dr. Abel, and (4) suffer from recurrent symptoms not controlled by conservative means, the performance of a well tolerated comprehensive operation (anterior disc excision and interbody fusion at both the L_4 and L_5 levels) would seem to be the logical solution. In this connection I would like to point out that during the last two years I have operated, by the anterior route, upon a number of physically fit persons beyond the age of sixty (the oldest being seventy-two) with uncontrollable radicular pain with and without lumbago, with excellent results. Heretofore we were reluctant to consider these persons for any except conservative treatment.

Dr. Abel's investigations have added another valuable and very specific objective diagnostic method: disordered motion at the lumbar facet joints which is dependent upon the non-support of a degenerated disc. I also want to point out the value of routine motion studies in surveying a large group of patients to determine those likely to get well with little or no definitive treatment from those with more serious problems.

Finally, lest the paper of Dr. Abel be misunderstood as an implication that myelography should be eliminated from the preoperative study, I will point out again, as he has, that positive myelograms are invaluable guides for localization; even normal myelograms have a certain value when interpreted with the patients' symptoms and persistent findings in mind, and will detect blocking intraspinal

neoplasms. Their judicious use in some, but not all, patients is to be recommended. Unfortunately, myelograms have definite value in only about half our cases. In completing this discussion on the diagnosis of disc disease, we should not forget to mention electrodiagnosis (electromyography), although this is not within the scope of Dr. Abel's paper. All methods should be utilized in the more difficult diagnostic cases.

H. Harvey Gass (Detroit, Mich.): I would like to confine my remarks to the paper on craniocerebral injuries by Drs. Hilst and Nielsen. With a creditable record, they pointed out the patients who do poorly and where new therapeutic weapons are needed. They discussed the evaluation of hypothermia and urea. These offer some hope, but the authors have accumulated insufficient experience to make a final opinion valid.

I would like to give special emphasis to the patient with injury to the brain stem whose condition is not too readily recognized and often poorly evaluated. Such patients are in a state of unconsciousness and decerebrate rigidity, sometimes of all extremities, but at other times one side only may be involved and sometimes the rigidity is confined mostly to the lower extremities. Along with this finding, there are pupillary disturbances present immediately at the time of the injury. These come from direct trauma to the mid-brain. Hyperthermia may also begin within a few hours, and may cause the patient's death unless corrected. There may be hyperhidrosis as well. These injuries result from trauma to the mid-brain as it strikes against the free edge of the tentorium by the inertia of the moving brain. These patients are serious problems but the outlook may not be as bad as it seems because, surprisingly enough, children and adolescents especially do well and even recover. Attention must be given to measures to combat hyperthermia and to the respiratory and urinary tract systems. It is also important to maintain electrolyte balance. It pays not to cease treatment on this particular group of patients.

I would like to say a word about angiography; I take issue with Drs. Hilst and Nielsen on this point. In my mind, it is an extremely valuable technic for identifying hematomas early, and it is very accurate. Only eighteen angiograms were done in this large series of cases and I feel this is too few.

W. D. Hilst (closing): In response to Dr. Gurdjian's question, our figures showed a fatal outcome in approximately one-third of 110 patients with a prolonged period of unconsciousness. We believe that the appearance of localizing signs and increasing intracranial pressure are more accurate in the prognosis, as previously noted.

The problem of arteriograms has been well covered by Dr. Gass. We do not decry their use, but emphasize that in most of these cases the decision of whether or not trephination is necessary can be made on clinical findings.

The final point we wish to make is that persistence is perhaps the most important point in caring for these patients. Thus, as noted, several patients were unconscious for weeks and yet made satisfactory recoveries.

D. N. Kluge (closing): In answer to Dr. Gurdjian's question, we attempt to accomplish as complete a preoperative evaluation as the condition of the patient warrants. This includes both detailed laboratory examinations, to rule out metabolic reasons for coma, and radiographic study.

A comparison of these preoperative studies with the final diagnoses revealed that they were occasionally misleading. The emphasis should be on performing trephination.

I agree with Dr. Gass on the value of arteriography. We performed eight such studies preoperatively. They were all helpful, and agreed either with a positive diagnosis of an intracranial lesion or with the operative findings that there was no subdural hematoma. We have been inclined to use this type of study more frequently and have found it increasingly helpful.

K. V. Cammack (closing): These enzyme studies in clinical medicine are very promising new developments. About twenty-five of these enzymes can be analyzed. The concept of actual biochemical biopsy of altered cellular physiology is an interesting one. We had some objections from various men on doing spinal taps on patients with injuries to the head. Only about 0.5 cc. of spinal fluid, a small amount, is needed, and we have not let a large amount run out.

Some of our patients had blood in the spinal fluid. There was not a concomitant elevation of the serum GOT when the spinal fluid GOT was elevated. A blood-brain barrier exists and even with the tear, no elevation was recorded. The blood in the spinal fluid will raise the GOT if the red blood cell is hemolyzed, because there is a high concentration of transaminase in the blood cell itself. Therefore, the initial tap should be centrifuged right away and the blood taken out of it. If the blood is already hemolyzed, it will not raise the transaminase more than 20 units, and you can allow for this. Of course, with these investigational patients we did more lumbar punctures than would be necessary. Some of these patients had a spinal leak from the ear, and the spinal fluid could be collected daily and hourly if desired. I think that if this proves to be valuable in prognosis, a large number of spinal taps will not be necessary.

The two patients who died without GOT elevation had injuries to the brain stem; injury to a small area in a vital spot was the cause of their death.

We are interested in the possibility of evaluating injuries to the spinal cord with these enzyme studies. Theoretically, if there is actual cellular destruction of the spinal cord there should be an elevation of the transaminase, while if there is merely compression it should be normal. This determination might prove valuable in deciding if decompression would be beneficial. Spinal fluid transaminase determinations in the prognosis of acute poliomyelitis or meningitis might be valuable also.

M. S. Abel (closing): I would like to stress the importance of correlating all x-ray criteria in making a diagnosis of discogenic difficulties, not just any one single item, whether it be myelography or any other diagnostic procedure.

Chemical Osteosynthesis

IRVING REDLER, M.D., *New Orleans, Louisiana*

From the Department of Orthopaedics, School of Medicine, Louisiana State University, New Orleans, Louisiana.

CHEMICAL osteosynthesis by means of a polyurethane polymer, Ostamer®, was described by Mandarino and Salvatore in 1958. The chemicals, a prepolymer and a catalyst, were mixed at the time of surgery and the resulting liquid polymer poured into a prepared bone cavity. The chemical reaction caused the polymer to foam and expand, fill the cavities, and bond to the bone surfaces. The plastic foam set in fifteen to twenty minutes and completely hardened twenty-four to forty-eight hours later. Weight bearing or functional use was then permitted. Their experimental studies in dogs demonstrated replacement of the polymer by new bone within eighteen to twenty-four months, its lacunar structure providing a framework for endochondral bone proliferation. No evidence of local or systemic toxicity was observed.

We have used Ostamer fixation in a variety of orthopedic and traumatic conditions to determine its applicability and efficacy. The patients, seven of whom were children, were carefully selected to provide an adequate test for this method. Fifty operations were performed on forty-one patients. They were: arthrodesis, nineteen operations; internal fixation of delayed and non-unions, eighteen; open reduction and internal fixation of fresh fractures, six; open reduction and fixation of pathologic fractures, three; osteotomy for malunion, three; and filling of bone defect, one. (Table 1.)

Conventional approaches were employed and tourniquets used whenever possible. Diaphyseal lesions were fixed by removing cortical strips of varying lengths from each fragment with a motor saw and hollowing the medullary cavity, which was then filled with Ostamer. Metaphyseal fixation required removal of a cortical strip from the diaphyseal fragment, and cavitation of the epiphyseal fragment followed by filling of the defect with the material. Arthrodesis of the knee, ankle, subastragalar joint and interphalangeal joints of the finger was performed by hollowing the articular end of each component bone, forming one large cavity crossing the center of the joint, and filling it with the polymer. The technic was later modified by placing pieces of cancellous bone, removed during preparation of the cavities, in contact with denuded portions of the joint surfaces to obtain bony union.

Arthrodesis of the hip was performed through a Smith-Peterson approach, in attempting to bond the Ostamer to prepared cavities in the femoral head and neck, and the

TABLE 1
DISTRIBUTION AND RESULTS

Type and Location	Total	Healed	Failed	Undetermined	Infected
Fresh fracture (6):					
Neck of humerus	2	2	..	..	1
Shaft of femur	2	1	1	..	..
Neck of femur	2	..	2	..	..
Pathological fracture (3):					
Mandible	2	..	..	2	1
Humerus shaft	1	..	..	1	..
Delayed and non-union (18):					
Humerus shaft	2	1	..	1	..
Humerus supracondylar	1	1	..	..	..
Radius	2	1	..	1	..
Ulna	3	2	..	1	..
Tibia	7	..	5	2	1
Femur	3	..	1	2	1
Malunion (3):					
Tibia	1	..	1	..	1
Femur	2	..	1	1	..
Bone defect (1):					
Tibia	1	..	..	1	..
Arthrodesis (19):					
Spine	4	..	..	4	2
Hip	2	..	1	1	2
Knee	3	..	2	1	1
Ankle	4	..	..	4	1
Subastragalar	5	..	..	5	..
Interphalangeal	1	..	1	..	1
Total	50	8	15	27	12

pelvis. In arthrodesis of the spine, bone grafts were applied to the roughened laminas and the polymer was poured over the denuded and undercut spinous processes, so as to bind them together and prevent motion in the operated segment of the spine.

The manufacturer's instructions for preparation of Ostamer were carefully followed. Manual mixing by rapid stirring with a wooden tongue blade was employed initially. Later, wire beaters propelled by a rotating motor saw were substituted for easier mixing. Whenever a proper quality of polymer "mix" was not obtained it was discarded, or, if poured, was removed from the bone cavity and a new batch prepared and poured. Complete fixation of the bone fragments was determined by gentle movement of the limb before the wound was closed. If motion between fragments was demonstrated, the material was removed and replaced.

Patients were immobilized postoperatively by plaster of paris or traction for a period of several days to two weeks. In some cases, because of apparent precarious fixation or subsequent failure of fixation, immobilization was continued for several months in an effort to obtain bony union. As a rule, weight bearing or functional use was permitted as soon as wound healing had occurred.

The period of postoperative observation extended from a maximum of seven months to a minimum of six weeks. Our present results, therefore, can only be evaluated as to maintenance of fixation and development of bony union. Fixation was considered successful if there was x-ray evidence of bony union by callus. The fixation was classified as a failure if any motion developed postoperatively. The maintenance of fixation without x-ray evidence of bony union was considered to be of undetermined status, capable of uniting or breaking at any time. By these standards, eight cases have been successful, fifteen have failed, and twenty-seven are still undetermined.

Seven of eleven operations of the long bone of the upper extremity have healed by subperiosteal callus formation and the remaining four are apparently holding although ununited. Conversely, only one of eighteen operations of the long bone of the lower extremity has united by callus formation, and six are still in an undetermined category. Eleven are known failures of fixation.

Four arthrodeses, two at the knee, one at the hip, and one at the proximal interphalangeal joint of the finger, have failed. The remaining fifteen are apparently holding but do not show any x-ray evidence of bony union.

The Ostamer column was discovered to have broken completely across at the fracture site in four patients. It was confirmed by reoperation in two cases of non-union of the tibia and one case of fracture of the femoral neck. The x-ray appearance of the other fracture of the neck of the femur was identical to the reoperated one. Failures of this type are due to insufficient strength of the material. They can probably be prevented by imbedding metallic reinforcement across the fracture site.

The Ostamer column pulled away from the bone cavity in eleven patients. This was confirmed by reoperation in seven, and it was demonstrated in the other four by stress x-ray films and manipulation under a fluoroscope. This group included the four unsuccessful attempts at arthrodesis, the tibial and femoral osteotomies, the gunshot fracture of the femur, and four non-unions, three of the tibia and one of the femur.

It is significant that fourteen of fifteen failures occurred in weight bearing locations. The one unsuccessful arthrodesis of the proximal interphalangeal joint of the finger was undoubtedly due to the fact that it was impossible to implant enough of the Ostamer in the medullary cavities of the phalanges.

Secondary repair of two non-united tibias, the gunshot fracture of the femur and the non-united supracondylar osteotomy of the femur was attempted with Ostamer. One tibial non-union that was additionally reinforced with an Eggers plate appears to be uniting and is ambulatory. The other one promptly broke and was immobilized in a plaster of paris cast in an effort to obtain union. The supracondylar osteotomy repaired with Ostamer alone broke and was immobilized in a plaster of paris spica. The gunshot fracture of the femur was reinforced with intramedullary metal plates. Because of a gap of over 2 inches between the bone fragments, it was immobilized in a plaster of paris spica. It appears to be holding, but is not united. One fracture of the femoral neck was reoperated and a femoral head prosthesis inserted. The medical condition of the other fractured femoral neck would not permit further intervention. One patient with failure

of fixation of an arthrodesis of the knee joint and a non-union of the shaft of the same tibia was amputated above the knee because of extensive infection and futility of obtaining union. The remaining unsuccessful fractures have been immobilized in plaster of paris in an effort to obtain bony union.

Wound infection of varying severity developed at different postoperative intervals in twelve patients. Seven involved arthrodeses; one, fixation of a displaced fracture of the neck of the humerus; three, fixation of the upper end of the tibia and lower end of the femur; and the remaining one, stabilization of a pathologic fracture of the mandible due to multiple myeloma. Three factors are believed to have contributed to this high incidence of infection. They are the apparent foreign body reaction of the Ostamer when it becomes loose in the bone, the necessity for extensive bone excavation in many of these procedures, and contamination by a carrier member of the operative group. Further study is being devoted to this.

There has not been any evidence of local tissue reaction in any of the cases healing by primary intention. There has been no observed evidence of systemic toxicity to date.

Specimens of Ostamer were removed from six reoperated patients and studied microscopically. They were taken from areas in intimate contact with the bone and from the center of the Ostamer mass. Most sections from the bone contact areas showed some degree of fibroblastic proliferation within the Ostamer lacunas. There was no evidence of osteoblastic activity in the more central portions of the Ostamer, even as late as four months postoperatively. These studies will be continued to determine if the Ostamer is replaced by bone in persons. It appears that many years of observation will be necessary to determine the ultimate fate of the imbedded material.

In conclusion, the advantages of immediate bone fixation and restoration of function that may be obtained by this method warrant further study in selected patients. On the basis of our experiences, the best prospects for success appear to be in fixation of the long bones of the upper extremity and the subastragalar and ankle joints.

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Chemical Osteosynthesis of Fractures and Non-unions of the Shafts of Long Bones of the Lower Extremity

BENJAMIN W. DROMPP, M.D., *Detroit, Michigan*

From the Department of Orthopedics, Wayne State University College of Medicine, Detroit, Michigan.

THE use of inorganic materials other than metals as internal fixation or as a material for "bone expander" in the management of fractures or bone defects has long intrigued surgeons. Three papers in the current literature emphasize that interest in this field is not lagging. Peltier of Kansas City has done much investigation on the use of plaster of paris as an expansion material to fill bone defects. He recently reported rather amazing results with this technic in five cases [1].

In the field of inorganic synthetic materials as internal fixation of fractures or for filling bone defects, Bloch of Australia and Mandarino of this country have recently reported their experiences [2,3]. Bloch reported two cases of non-union of long bones that were treated by an ethoxyline resin used as internal fixation in lieu of plaster immobilization. In a preliminary report he noted satisfactory results. However, the technic he reported would seem to be quite cumbersome for it required the use of a portable blowtorch at the operating table to cure the resin as it bonded to bone. This difficult technic and the chance of contamination of the sterile field that it offers would seem to relegate this material to an impractical type of surgery.

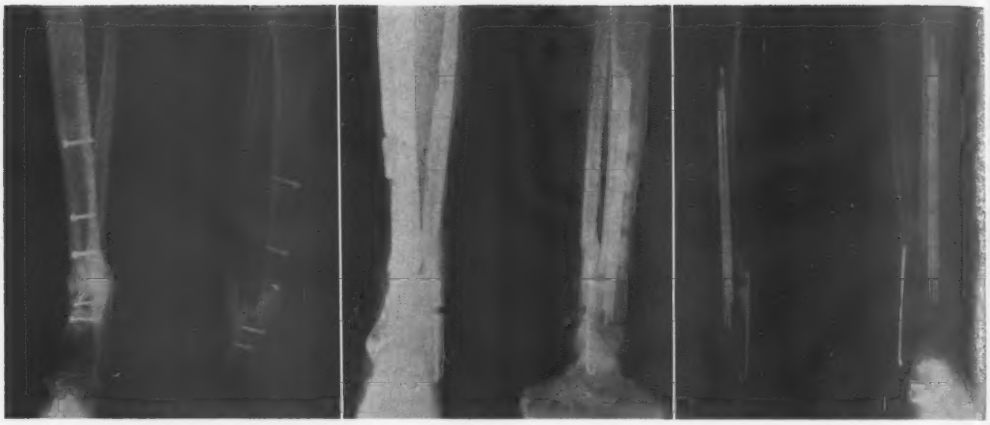
In 1958 Mandarino and Salvatore, having already conducted animal experimentation and toxicity tests, presented the results of six cases in which another synthetic material had been used as internal fixation for fractures. This material was poured in a liquid state after the prepolymer had been mixed with a catalyst that would convert the liquid into a solid foam polymer approximately twenty minutes after the mixing. This material was one of the polyurethanes that the manufacturer* has given the trade name of Ostamer.® In addition to Ostamer, they supplemented the synthetic material with metal rods that were incorporated into the polymer mass much like reinforcing rods in concrete. These patients were ambulated rather quickly after surgery in braces, and plaster immobilization was not used for any other than the forty-eight– to seventy-two–hour "cure" period that this material requires. They reported satisfactory results in all cases.

This paper presents additional material concerning the clinical use of Ostamer. An attempt was made to reduplicate Mandarino's work and his exact surgical technic was followed. His postoperative regimen was modified as we acquired experience with the use of this material. Because we encounted complications not reported before, we were forced to alter our surgical technic somewhat also. These improvements or modifications are reported in this paper and the indications for these are outlined.

Our experience with this synthetic material dates from January 1959, and in a six-month period we performed fifteen procedures on fractures of the shafts of the long bones of the lower extremities. Although none of our material constitutes a long term follow up, all these patients have been followed up for more than two months, so that at least all immediate postoperative complications can be reported.

Our material consisted of four fresh fractures of the tibia, eight non-unions of the tibia, one fresh fracture of the femur and two non-unions of the femur. Needless to say, all cases were especially selected because of some problem

* The Wm. S. Merrell Co., Cincinnati, Ohio.

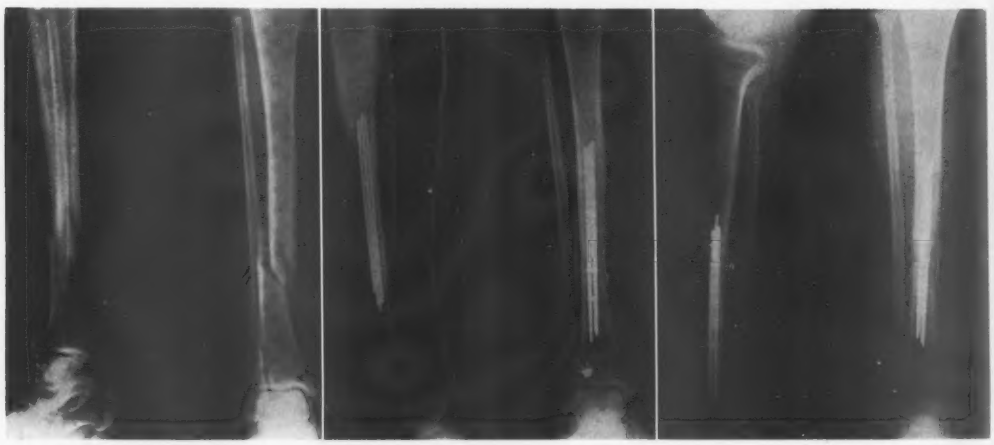


1 2 3

FIG. 1. CASE 1. Non-union of left tibia of five years' duration.

FIG. 2. CASE 1. Left tibia two weeks after insertion of sliding bone graft using Ostamer and Mandarino pins as internal fixation.

FIG. 3. CASE 1. Status of left tibia six months after surgery using Ostamer.



4 5 6

FIG. 4. CASE 2. Spiral fracture of right tibia with such swelling that three weeks of traction preceded surgery.

FIG. 5. CASE 2. Immediate postoperative x-ray film of right tibia.

FIG. 6. CASE 2. Status of right tibia five months after surgery.

peculiar to the patient and Ostamer is not used routinely in our institution.

The procedures on the femurs were not complicated by wound dehiscence, infection or excessive swelling, and after an immediate postoperative period of two weeks in skin traction the patients were ambulated on crutches when the wound was well healed. Weight-bearing was not permitted immediately. We encountered excessive postoperative swelling, wound dehiscence and skin slough in some of the patients with tibial fractures and made modifications to combat these as we progressed in our investigation.

CASE REPORTS

CASE 1. A thirty-four year old man had non-union of the left tibia of five years' duration. (Fig. 1.) Treatment consisted of a sliding bone graft and internal fixation using Ostamer and

7 8 9

FIG. 7. CASE 3. Non-union of left tibia resulting from open comminuted fracture.

FIG. 8. CASE 3. Patient placing weight on left tibia ten weeks after surgery using Ostamer.

FIG. 9. CASE 3. Status of left tibia sixteen weeks after surgery.

10 11 12

FIG. 10. CASE 4. Severely swollen, comminuted fracture of distal right tibia before surgery.

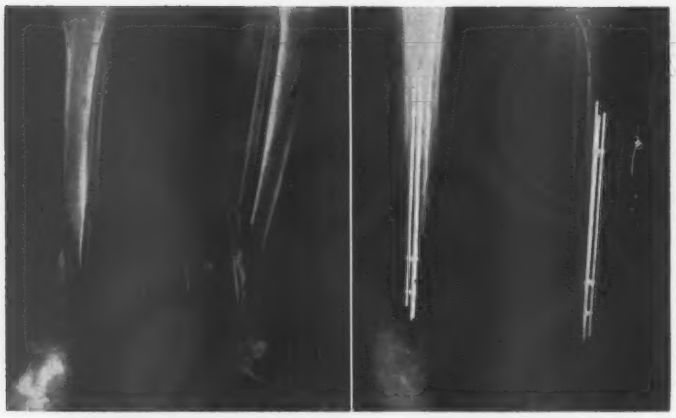
FIG. 11. CASE 4. Skin slough of right leg six weeks after surgery using Ostamer.

FIG. 12. CASE 4. Status of healing of right tibia sixteen weeks after surgery.

Mandarino pins. Posterior mold immobilization was maintained for two weeks, and a dressing change at this time revealed a wound dehiscence. Roentgenographic examination disclosed good alignment. (Fig. 2.) An attempt at secondary closure failed. The status of bone healing at six months is shown in Figure 3. The wound defect was smaller and we feel that this dehiscence was due to excessive surgical trauma and could have happened in an ordinary bone graft procedure.

CASE 2. A fifty-eight year old man required skeletal traction for a fracture of the right tibia until skin blebs and severe swelling subsided. (Fig. 4.) Three weeks later, open reduction using Ostamer and Mandarino pins as internal fixation was performed. (Fig. 5.) Immobilization was discontinued in two weeks but because of severe swelling, dependency was curtailed for an additional six weeks. Partial weight-bearing was then instituted and at the end of sixteen weeks he was bearing full weight. The status of bone healing at five months is shown in Figure 6.

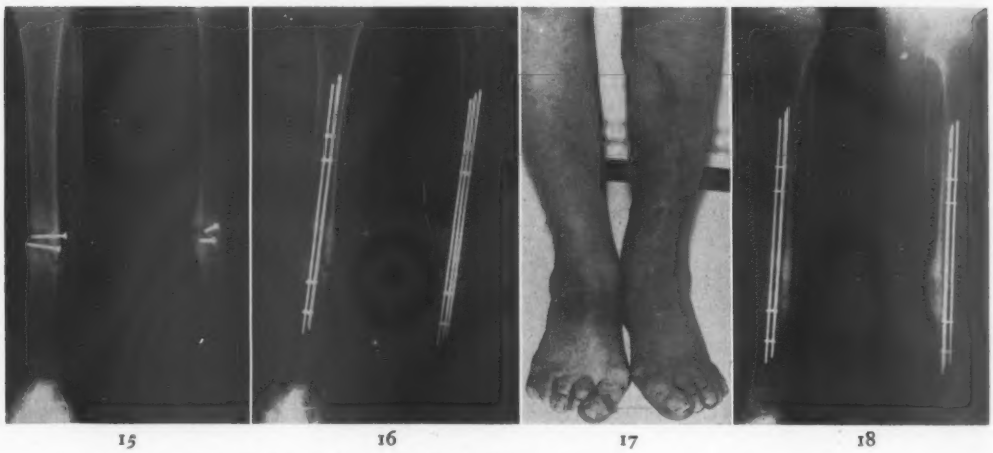
Because of these complications, we used plaster immobilization for four to six weeks in



13 14

FIG. 13. CASE 5. Non-union of left tibia resulting from open, comminuted fracture nine months previously.

FIG. 14. CASE 5. X-ray film taken sixteen weeks after surgery using Ostamer. Persistent osteoporosis and probable non-union are evident.



15 16 17 18

FIG. 15. CASE 6. Non-union of left tibia before surgery.

FIG. 16. CASE 6. Status of left tibia four weeks after surgery using Ostamer.

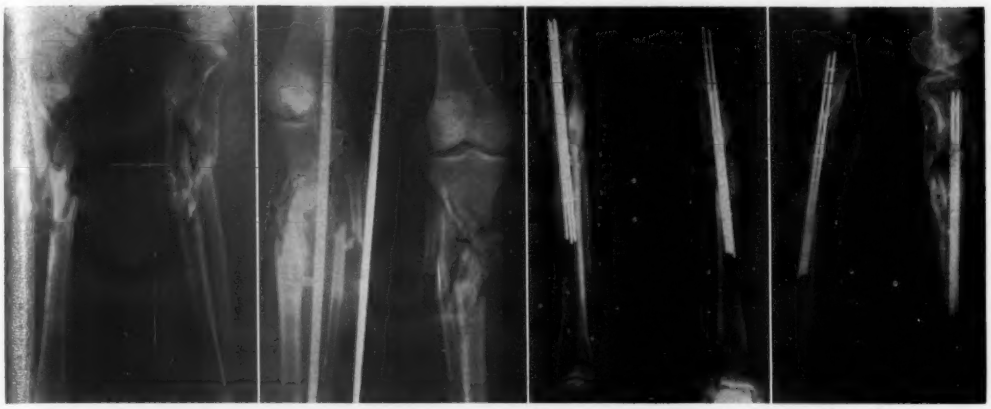
FIG. 17. CASE 6. Patient bearing part of her weight on left tibia six weeks after surgery.

FIG. 18. CASE 6. Status of healing of left tibia twelve weeks after surgery.

most of the other patients with tibial fractures in order to insure adequate soft tissue healing before initiating any weight-bearing.

CASE 3. A twenty-one year old man had non-union of the left tibia. (Fig. 7.) Eight weeks after surgery partial weight-bearing was begun and he was bearing full weight in twelve weeks. Minimal drainage was noted in the tenth postoperative week. (Fig. 8.) The status of bone healing at sixteen weeks is shown in Figure 9.

CASE 4. A fifty-eight year old man had a comminuted distal right tibial fracture (Fig. 10) which was treated by open reduction and internal fixation (using Ostamer and Mandarino pins) when swelling subsided three weeks after injury. When the cast was removed in six weeks, a skin slough



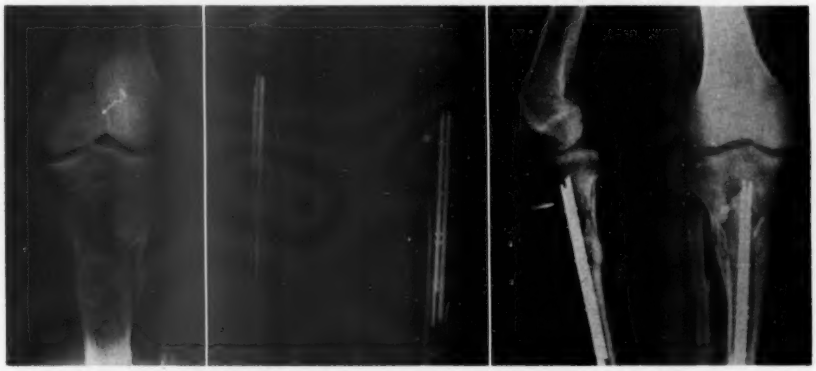
19 20 21 22

FIG. 19. CASE 7. Status of non-union of proximal right tibia ten months after injury.

FIG. 20. CASE 7. Original severely comminuted, open fracture of right tibia.

FIG. 21. CASE 7. X-ray film taken immediately after surgery.

FIG. 22. CASE 7. Status of right tibia ten weeks after surgery when immobilization was discontinued.



23 24 25

FIG. 23. CASE 8. Articular fracture is healed, but healing of proximal tibia is delayed after eight weeks of traction.

FIG. 24. CASE 8. X-ray film taken immediately after surgery.

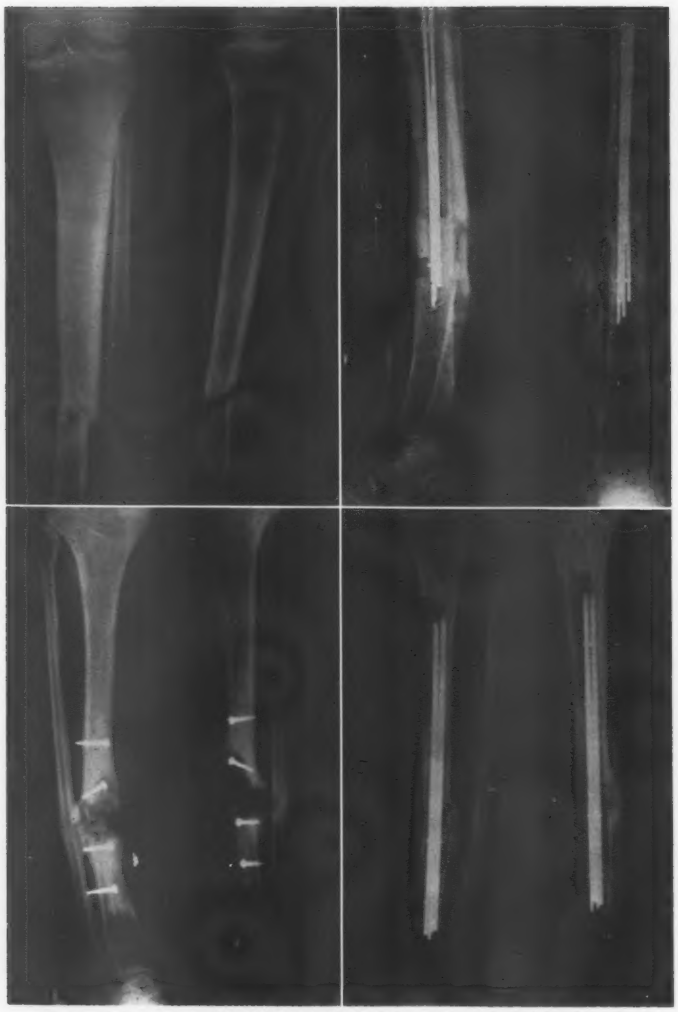
FIG. 25. CASE 8. Status of healing of fracture seven weeks after surgery using Ostamer.

was found between the operative incision and a relaxing incision. (Fig. 11.) This has since been successfully skin grafted, and the status of bone healing at four months is shown in Figure 12.

CASE 5. A fifty-eight year old woman had non-union of the left tibia. (Fig. 13.) Insertion of a sliding bone graft using Ostamer and Mandarino pins was difficult because of the severe osteoporosis of the distal fragment. Plaster immobilization was discontinued after six weeks but weight-bearing is still not allowed because of the poor healing suggested in the x-ray films (Fig. 14) taken sixteen weeks after surgery.

CASE 6. A seventy year old woman had non-union of the left tibia. (Fig. 15.) Immobilization was discontinued at four weeks (Fig. 16) and partial weight-bearing was started at six weeks. (Fig. 17.) Bone healing twelve weeks after surgery is shown in Figure 18.

CASE 7. A thirty-three year old man had non-union of the right tibia (Fig. 19), having had an open fracture ten months earlier. (Fig. 20.) A sliding bone graft using Ostamer and Mandarino pins (Fig. 21) was supplemented by a plaster cast for ten weeks because of the large gap spanned by the Ostamer. X-ray films at this time suggested



26 27

28 29

FIG. 26. CASE 10. Non-union of right tibia of six months' duration.

FIG. 27. CASE 10. X-ray film taken four weeks after surgery.

FIG. 28. CASE 11. Non-union of two years' duration in right tibia.

FIG. 29. CASE 11. X-ray film taken after surgery using Ostamer.

enough healing to discontinue immobilization. (Fig. 22.)

CASE 8. A fifty-eight year old man had a fracture of the proximal right tibia that involved the articular surface. A sliding bone graft using Ostamer and Mandarino pins was inserted after eight weeks when the articular fracture had healed. (Fig. 23.) The postoperative status is shown in Figure 24. Bone healing seven weeks postoperatively is shown in Figure 25.

Case 9. In this sixty-seven year old man, Ostamer was used to treat a fresh fracture of the distal right tibia. Unfortunately, this patient suffered a cerebral vascular accident and died three weeks after surgery. Excessive surgical trauma produced a wound dehiscence in this patient.

CASE 10. A fifty-three year old man had non-union of the right tibia. (Fig. 26.) Four weeks after a sliding bone graft was inserted, using Ostamer and

FIG. 30. CASE 12. Non-union of two years' duration.

FIG. 31. CASE 12. Status of healing of right tibia fourteen weeks after surgery.

FIG. 32. CASE 13. Status of right femur four years after fracture. Original hardware removed because of serous drainage.

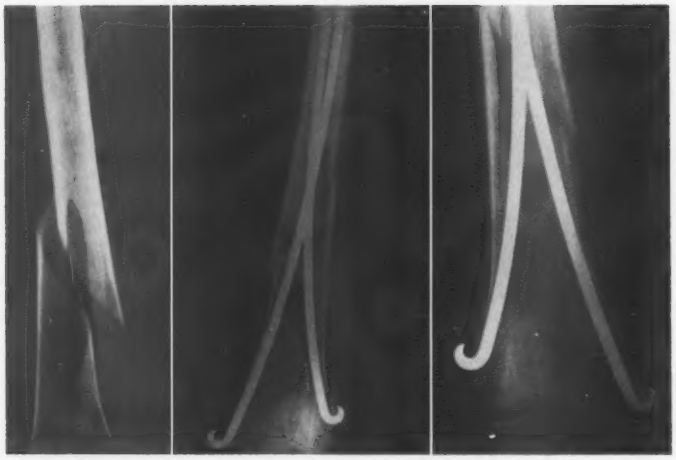
FIG. 33. CASE 13. Status of femur seven weeks after insertion of bone graft using Ostamer and Rush rod for internal fixation.

Mandarino pins (Fig. 27), his cast was removed. He was started on partial weight-bearing six weeks after surgery.

CASE 11. A forty-six year old woman had non-union of the left tibia of two years' duration. (Fig. 28.) A previous graft had failed because of infection. Surgery, using Ostamer (Fig. 29), was followed by minimal drainage. After removal of the plaster cast at three weeks, she was ambulated in a brace in order to return to work.

CASE 12. In this forty-nine year old man, infection caused a failure of a bone graft in the right tibia. (Fig. 30.) Four weeks after surgery, using Ostamer, he returned to work wearing a long leg brace. Moderate drainage developed, and the status of his bone healing at fourteen weeks is shown in Figure 31.

CASE 13. In this sixty-seven year old man, a subtrochanteric fracture failed to unite. Figure 32 shows the non-union after metallic internal fixa-



34 35 36

FIG. 34. CASE 14. Spiral fracture of distal femur before open reduction.

FIG. 35. CASE 14. X-ray film taken immediately after operation.

FIG. 36. CASE 14. Status of fracture healing twelve weeks after surgery.

tion had been removed four years after fracture. The status of bone healing seven weeks after bone grafting, using Ostamer and a Rush rod for internal fixation, is shown in Figure 33.

CASE 14. A sixty-one year old man had a spiral fracture in the distal left femur. (Fig. 34.) A sliding bone graft and Ostamer were used to give added stability to two Rush rods. (Fig. 35.) Postoperative balanced suspension permitted immediate knee immobilization, and partial weight-bearing was started in four weeks. Twelve weeks after surgery (Fig. 36) increased weight-bearing was urged.

CASE 15. In this forty-six year old man, a comminuted fracture of the right femur was treated by traction and hip spicas. (Fig. 37.) Ten months after fracture he still had insufficient healing to permit weight-bearing. (Fig. 38.) Insertion of a sliding bone graft, using Ostamer and Mandarino pins as internal fixation, was followed by partial weight-bearing in eight weeks and full weight-bearing in twelve weeks. (Fig. 39.) The status of bone healing at sixteen weeks is shown in Figure 40.

COMMENTS

An exacting analysis of our fifteen cases would suggest that we experienced difficulty in most of them and that Ostamer does not present any material advantage to the surgeon in the treatment of fractures or non-unions in the long bones of the lower extremity. However, we believe that Ostamer has proved to be quite an asset in the management of certain difficult cases, and with this added experience we are now using this material with less difficulty than we first encountered. It should be noted that the three cases involving the femur were treated without subjecting the patient to the discomfort of a hip spica. The fact that in these three patients the soft tissue wounds healed without difficulty would indicate that the superior anatomic advantages of the increased muscle mass and skin pliability of the thigh readily permit the extensive exposure required for use of this material in the femur.

These anatomic advantages are certainly not present for surgery of any type on the tibia. At least one complication was noted in most of the cases involving the tibia, but we believe that these could have been present in any type of procedure in this region. Table 1 reveals that of our twelve patients, in whom Ostamer was used to treat a fracture or non-union of the tibia, nine were over forty-five years of age and seven had had either an open fracture originally or had had infection following surgery. The age of the patient, poor peripheral circulation and previous infection are known to prejudice the result in any surgical procedure on the tibia. Counting wound dehiscence, skin slough, non-union and infection in a previously clean case as major complications, only five of our patients suf-

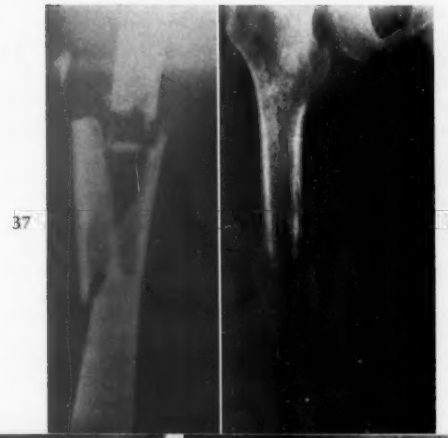


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FIG. 37. CASE 15. Original fracture in May 1958.

FIG. 38. CASE 15. After ten months, healing was not sufficient to permit weight-bearing.

FIG. 39. CASE 15. Patient bearing weight on right leg eight weeks after surgery.

FIG. 40. CASE 15. Healing of fracture sixteen weeks after surgery.

TABLE I
USE OF OSTAMER IN TWELVE CASES OF NON-UNION OR FRACTURE OF TIBIA

Case No.	Age (yr.)	Previous Infection or Open Fracture	Severity (Major or Minor) and Type of Complication
1	34	Yes	Major: Wound dehiscence
2	58	No	Minor: Excessive swelling
3	21	Yes	Minor: Minimal Drainage
4	58	No	Major: Skin slough
5	58	Yes	Major: Non-union
6	70	No	Minor: Minimal drainage
7	33	Yes	Minor: Immediate instability, late drainage
8	58	No	Major: Drainage
9	67	No	Major: Wound dehiscence
10	53	Yes	None
11	46	Yes	Minor: Drainage
12	49	Yes	Minor: Drainage

fered one of these. We noted that all these five patients were either over fifty-five years of age or had a history of previous infection. Only one patient had no immediate complication and six had a minor complication, as noted in Table I.

Despite any complication, in all except two of the twelve patients the bone lesion is rapidily healing or has already healed. Only one of the twelve patients was immobilized in a cast for more than six weeks, and only three wore braces. This suggests that rapid mobilization of the extremity is associated with rapid bone healing when Ostamer is used for internal fixation.

SUMMARY

1. Our experience in the use of a synthetic polyurethane (Ostamer) in the treatment of fifteen fractures or non-unions in the shafts of the long bones of the lower extremity is presented.

2. We detected no allergic or toxic effects in our patients that could be attributed to Ostamer.

3. The modifications we employed to counteract the complications noted with the use of Ostamer are outlined and the rationale of these modifications is explained.

4. Having found methods of decreasing the aforementioned complications, we believe that Ostamer, as a bone adherent material, can be successfully used in the treatment of fractures and non-unions of the shafts of long bones, and we believe that chemical osteosynthesis may eventually have a place in the armamentarium of the surgeon.

5. Investigation of this material should be continued, and the results of these investigations should be evaluated before this material is accepted for general use by the medical profession.

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DISCUSSION OF PAPERS BY DRS. REDLER AND DROMPP

J. R. MOORE (Philadelphia, Pa.): I enjoyed the presentation of these two papers. The authors have been very frank and careful in the analysis of their results. A review of the study of Ostamer has been my fortune, and I have had an opportunity to see many results of the research work and also some of the operations of Dr. Manderino in Philadelphia. It seems to me that the results at this particular point of progress in this field are expressed in the results given in the two papers. It is obvious that further experimental work in the animal field is necessary.

The high percentage of failures is appalling, and they are conclusive evidence that Ostamer should be reserved at present for the experimental animal. The number of cases reported by both authors is sufficient to constitute ample human research. They should be followed closely and a supplementary report given with a minimal three-year follow up.

T. OUTLAND (Harrisburg, Pa.): Dr. Clay Murray has said, "Ideal treatment of a fracture would be to wish it into position and hold it there by moral persuasion." Chemical osteosynthesis might be a further step in that direction. Certainly it is on trial, and the value of the method is not yet an established fact. However, it cannot be lightly brushed aside by a few snide remarks. It has the disadvantage of being spectacular, flamboyant perhaps, but only because many of our methods are rather homespun. When placed alongside prosthetic replacement of the aorta or other large vessels, open heart surgery and similar developments of recent years, it appears much less spectacular.

I would like to mention three cases which I think

presented problems not satisfactorily handled by orthodox methods. One was a patient with non-union of the humerus following osteotomy for internal rotator contracture of the shoulder. There was failure of union six months postoperatively; Ostamer plus rods and an inlay graft were used in the repair.

A second patient with a stress fracture of the femur had been operated upon for non-union two and a half years previously. I left the medullary nail in place for about two and a half years because the radiologist reported the fracture was not yet solid. I finally removed it and a month later there was a stress fracture below the site of the previous non-union. Bone grafting was done with rods, Ostamer and an inlay graft.

The third patient had a fracture of the clavicle with a large, completely detached butterfly fragment. A real problem is presented in holding such a fracture reduced and making the patient comfortable. An intramedullary wire and Ostamer were used to stabilize the butterfly fragment.

As Dr. Moore suggested, the essayists should not persist in accumulating a still larger series in view of the many unsatisfactory results in certain types of cases. The contribution has been worthwhile in a negative if not in a positive way. My attitude about the method in the authors' hands was summed up by Dr. Hugh Cabot many years ago when, in commenting on what he thought were promiscuous, unnecessary cystoscopic examinations, he stated, "I don't mind if they pursue science up a tree as long as they don't pursue it up my tree."

C. G. Johnston (Detroit, Mich.): I want to congratulate Drs. Redler and Drompp on being very careful in their presentations. Sometimes with new material, enthusiasm overshadows some of the defects of what you are enthusiastic about. The authors have looked at Ostamer carefully and have presented something in the way of a follow-up study on a subject which we were concerned about when it was first presented a year ago. I can see no particular advances in the methods of treating fractures. As you remember, when pins were first used in hips and much interest was shown, many immediately got their patients up for weight-bearing. It is necessary to put pins in with Ostamer as well, to hold the material in position; I wonder whether early weight-bearing is really reasonable, if it is the sort of thing to start so early (even with Ostamer) and if not, what advantage does Ostamer have?

One other point that concerns most of us is the large amount of foreign material which is put in these areas. I wonder if this material is non-reactive, and if so, how one can expect it to stimulate a great deal of growth in the bone; if the bone is even suspected of having a reason for growing into it, it seems to me that smaller amounts should be used.

It is important that we have these reports now, for they throw some doubt on any positive advantage of this material. All too often these materials become available and everyone uses them with disastrous results. At our institution we have insisted that only one person gain experience with this, primarily because we believed that he could much better control it and we could get a series of studies which would show its value.

I hope that these reports will slow down at least the possible promiscuous use of this material, which at first raised a great deal of hope. I doubt if we can say it is useless now, but I think we can almost say it will offer nothing of advantage in the treatment of fractures, non-united or fresh; surely in a fresh fracture we do not need it.

W. H. Moncrief, Jr. (Washington, D. C.): At Walter Reed, we have only used this material in the experimental animal, and what I have to say does not have any clinical background. However, we have put it in almost every animal imaginable. There are two comments in the presentations I would take exception to: One is the reference to this material as "bone glue" and the other is "chemical osteosynthesis." By no stretch of the imagination is polyurethane plastic a glue. It will not glue. There is a mild bonding between the polymer and the bone, but this is certainly compromised by any serum or blood in the marrow cavity. "Chemical osteosynthesis" is also a problem. If one looks at the materials that go to make up polyurethane, one might well be amazed that new bone will grow into it. We should be satisfied with the fact that to date we have no evidence that polyurethane, *per se*, inhibits bone growth. We should refrain from the term "chemical osteosynthesis."

Polyurethane polymer is a di-isocyanate resin that is mixed with a catalyst to result in the polymer reaction. It is a finite reaction and it requires a certain amount of catalyst mixed with a certain amount of resin to get the true polymer. If any blood or serum mixes into it, a different kind of polymer is obtained—a brittle polymer which will not bear weight. I wonder if when Dr. Redler started weight-bearing in his group of patients with disorders of the lower extremity, they might have been bearing weight on the modified polymer.

We have put this material in an obligate weight-bearing animal, the burro. This demonstrates very well that this is not a glue. This material is an absorbable intramedullary nail, and one must place enough plastic proximal and distal to the fracture site so that it acts as an intramedullary nail. The human femur has a large medullary cavity and the burro, a very small one. While we

could approximate the bone ends with plastic in the burro, we just could not get enough material into the bone for the animal to bear weight on the leg. Even a nail or pins that would fit this narrow space would be unlikely to support the weight of the animal.

We performed a "sleeve" resection of the radius of the dog. The periosteum was resected back about 1 cm. on either side of the bony defect. This animal was sacrificed about eleven months after the material was put in the radius. The ulna was left intact, and new bone had grown about and replaced the polymer.

Because polyurethane plastic has a biologic half life in experimental animals of ten months, we have been worrying about its mobilization pathways. It is a big polymer and where does it go? Is it picked up by the reticuloendothelial system? We are trying to solve this. Because this polymer is a mixture of materials it is extremely difficult. While a C^{14} tag would have been better technically, it was too expensive for us. We settled on a tritium tag (where this polymer is tagged, we do not know). This tritium-tagged polyurethane (as a dry powder) was placed intramuscularly in rats. The initial peak of excretion on the second day was, we believe, "wash-off" with a subsequent fall to background. By the tenth postoperative day the rats were putting out significant levels of tagged fragment, peaking about the thirteenth day. By thirty days the animals were excreting only minimal amounts. This has continued at this level for a year. Some time ago we were able to place some of our tagged polyurethane in a patient with a pathologic fracture of the proximal portion of the femur. The fracture was immobilized by metallic fixation and the polyurethane powder simply placed in the fracture site. To date, the patient has handled the material not unlike the rat.

Once again I would like to thank the essayists. I think they have made a real contribution in bringing together this group of patients. There are a lot more being treated around the country and I think they should be followed up very carefully.

I. Redler (closing): We were very interested in obtaining successful fixation of fractures of the neck of the femur. If this could have been accomplished, it would have been a remarkable advance in orthopedic surgery.

We are presently conducting engineering studies to determine the strength of Ostamer when used in situations that we encountered clinically. We are also trying to determine if there is any bonding strength between the material and the bone.

It was interesting to observe that we had many failures of fixation when we were able to use a tourniquet during operation. Conversely, we had many successful results in areas in which we were unable to obtain a bloodless field because of the impossibility to apply tourniquets.

We intend to follow up our patients as long as possible, and we hope to be able to present a final report based on future observations.

I think this material is a prototype of other materials that will be easier to use, will have greater strength, will bond with much more certainty to bone, and will be less toxic in their local reactions.

Benjamin Drompp (closing): I should like to add that Dr. Redler has very well summed up my attitude on this subject also, and I think we will both like the opportunity to present a follow-up report on observations of this material.

The Use of Intramedullary Prosthetic Replacement in Fractures of the Femoral Neck

ROLLA D. CAMPBELL, JR., M.D., JOSEPH B. MASON, M.D., PHILIP D. WILSON, JR., M.D. AND PRESTON A. WADE, M.D., *New York, New York*

THE high incidence of early and late complications following treatment of subcapital fractures of the femur by standard methods of reduction and internal fixation continues to reemphasize the problem created by these particular fractures. Mortality rates vary from 6 per cent reported by Neer [7], 9.3 per cent by the Campbell Clinic [9] and 11.6 per cent by the Fracture Committee of the American Academy of Orthopaedic Surgeons [1], to 23 per cent three months after injury as indicated by Larson [4]. Instances of non-union have been reported at 15.3 per cent by Boyd and George [2] and 33 per cent by Day and Hinchey [3]. (Fig. 1.)

The report from the Campbell Clinic states that aseptic necrosis developed in 32 per cent of the patients who had union of the subcapital fractures, which raised the failure rate to almost 50 per cent. This is consistent with the rate of 40 per cent aseptic necrosis reported by the Fracture Committee of the American Academy of Orthopaedic Surgeons and the 33 per cent reported by Larson. (Fig. 2.)

Thus there is a pressing need for a method of treatment for subcapital fractures, especially in elderly patients, which would at least be as well tolerated as reduction and internal fixation, permit early ambulation and withstand the demands of prolonged use.

O'Brien states that he and most of the orthopedic surgeons in St. Louis invariably treat subcapital fractures of the femoral neck in elderly patients by immediate (primary) prosthetic replacement [8]. The opinion of Dr. Fred Thompson is quoted in the following conservatism:

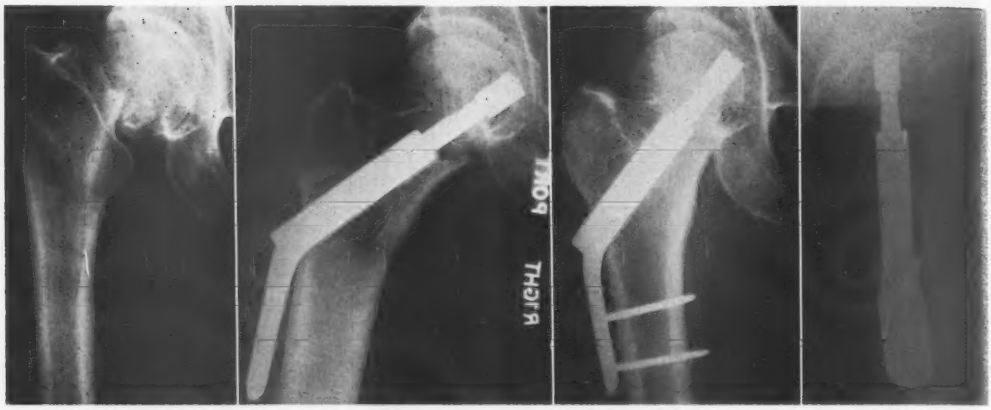
"One's surgical judgment may be influenced more by fascination for the new surgical tool than by sound orthopedic dicta. More often, it is a case of one's surgical judgment being influenced by the immediate advantages, economically and functionally, to be obtained from an artificial hip rather than the long term advantages of a costly, longer convalescent procedure of primary hip nailing. Often the judgment of the surgeon is based on his own particular experience with the type of fracture involved than on the over-all picture of what is to be expected with that special fracture throughout the land." [11].

These distressing figures and contrasting opinions have stimulated us to review all cases of prosthetic replacement of the femoral head for subcapital fractures. The patients studied were treated at The Hospital for Special Surgery and New York Hospital, both before and after formation of the Combined Fracture Service in 1954.

STATISTICAL DATA

A total of 132 cases were available for study. In forty-four of these, primary replacement of the femoral head had been performed. In eighty-eight, prosthetic replacement of the femoral head had been used as a secondary procedure after failure of initial treatment by reduction and internal fixation.

The average age of patients who received primary replacement of the femoral head was seventy-two years. The youngest was thirty-nine years old and the oldest eighty-eight. The age of patients in whom the prosthesis was used secondarily averaged sixty-six years. In this



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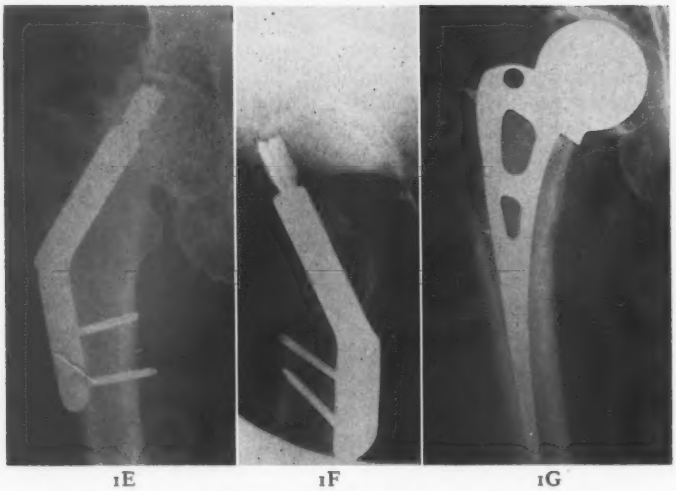

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FIG. 1. A, November 12, 1958. This badly displaced subcapital fracture occurred in a seventy-one year old woman. B, November 13, 1958. A Ken-Pugh nail was used in fixation. C and D, December 9, 1958. X-ray films three and a half weeks later show impaction of the fracture site in valgus position with the sliding mechanism of the nail performing according to its design. The nail appears in optimum position in both views. E and F, February 13, 1959. Anteroposterior and lateral views three months after nailing show that non-union of the fracture site and complete disruption of reduction have occurred, and that the nail has cut through the superior and anterior portions of the head which has slid off inferiorly and posteriorly. This non-union occurred in spite of secure fixation in good position, in a cooperative patient who did well with crutches. G, March 17, 1959. An early postoperative view of the hip after insertion of Austin Moore prosthesis. Six months later this patient reported no pain, no limitation of abduction and did not require the use of a cane or crutch. She had normal range of motion in the operated hip.

group, the youngest was thirty years old and the oldest eighty-eight.

More females than males were involved in an almost exact 3:1 ratio in both groups. Among patients receiving primary prosthetic replacement of the femoral head, thirty-four were females and ten, males. In secondary use of the prosthesis, there were sixty-six females and twenty-two males.

INDICATIONS FOR PRIMARY PROSTHETIC REPLACEMENT

Decisions for primary replacement arthroplasty for fractures of the femoral neck have,

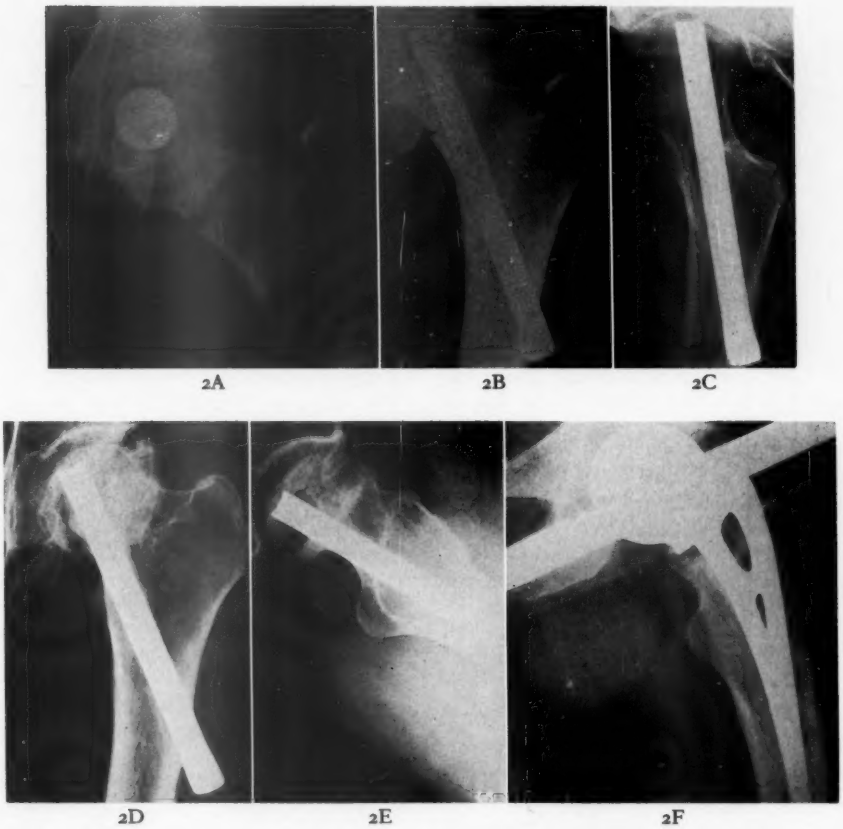


FIG. 2. A, December 18, 1952. This vertical fracture occurred in a fifty-two year old woman. B and C, December 29, 1952. Excellent reduction and secure fixation in valgus position are shown in these two views. D and E, May 2, 1956. In spite of union, aseptic necrosis developed and caused severe changes in the head of the femur as noted three and a half years later. F, May 14, 1956. Austin Moore replacement arthroplasty was carried out. Two years later there was a normal range of motion and tolerance of ambulation for three or four blocks with little pain, with the use of a cane.

for the most part, been made cautiously. This may be due to conservatism in using a new method which sacrifices one-half of the hip joint. These cases may be grouped into the following categories:

Failure of Reduction or Nailing Efforts. This occurred in ten instances. In one, open reduction was resorted to and failed. In another, efforts to obtain closed reduction failed and the operator decided to use a prosthesis. In eight cases, closed reduction and nailing procedures were so unsatisfactory that prompt operation for replacement arthroplasty was performed.

Local Problems at the Fracture Site. In eighteen cases, primary replacement arthroplasty was performed because of unfavorable anatomic considerations at the site. These included six cases in which the fracture was so comminuted as to defy fixation efforts. There were two instances of radiation necrosis of the femoral neck, three of pathologic fractures from severe osteoporosis, and six in which changes had occurred in the fracture site because of a delay in treatment of two weeks or more after injury. In the latter six cases, all elderly patients, an impacted fracture was thought to have occurred earlier and caused gradual absorption

of the neck of the femur before actue symptoms developed. Primary replacement arthroplasty was indicated in one case because of fracture of the head of the femur.

General Condition of the Patient. Primary replacement arthroplasty was selected for five patients whose general condition prohibited the proper use of crutches. This decision was made in four instances because of moderate to severe Parkinson's disease, and in another because of a contralateral weakness from a previous cerebrovascular accident. In one case, primary replacement arthroplasty was decided upon because the patient had irreversible malignancy in another part of the body; life expectancy was not long enough to be wasted in invalidism waiting for the subcapital fracture to heal.

Combination of Problems at the Fracture Site and General Condition of the Patient. In the remaining ten patients who received primary replacement arthroplasty, the prosthesis was used because it appeared to offer a quicker and more certain return to ambulatory, self-sufficient existence than would have been the case with standard reduction and internal fixation. These were elderly patients with Pauwel's type II or III displaced subcapital fractures.

INDICATIONS FOR SECONDARY REPLACEMENT OF THE FEMORAL HEAD

Secondary replacement of the femoral head was necessary in all eighty-eight patients because there was evidence of failure of treatment by reduction and internal fixation. There were seventy-five instances of non-union with or without necrosis, and six cases of necrosis despite union. Insufficient data prevented such determination in seven cases.

This study includes only those instances of subcapital fractures in which failure of the original treatment was followed by arthroplasty; it does not include many cases in which uncomplicated healing may have ensued following similar surgical circumstances. Nevertheless, this group represents a majority of the failures, and each case offers lessons in retrospect. Reasons for failure of original treatment have been roughly categorized into the following groups:

Failure to Obtain Anatomic or Stable Reduction. Massie [5] reported excellent results in nailing subcapital fractures, which he attributed in part to his methods of securing stability of the fragment of the femoral head by displacing the neck under it medially, and to the use of full internal rotation of the thigh to bring about anatomic locking of the fragments. Therefore, in this study careful attention was given to the type of reduction secured.

Unsatisfactory reduction either on the basis of Massie's criteria or from tilt of the fragment of the head out of its anatomic position (anteriorly, posteriorly or into a varus position or inferior displacement) occurred in seven of the thirty-eight patients who were later treated by secondary replacement arthroplasty. Nonunion and necrosis followed one instance in which the head was fixed anteriorly and tilted and displaced superiorly, and in another in which the head had been nailed in some degree of varus. In five others, fixation with the head in a posterior tilt resulted in failure.

Failure to Gain Secure Fixation of the Head Fragment. In seven patients, the cause for failure seemed to be due to inadequate fixation caused by incomplete penetration of the head fragment by the Smith-Petersen nail. The head thus fell off the nail into a varus position and tilt. In four cases this complication developed in the first month and in three others in the first three months after nailing.

Combination of Failure to Obtain Adequate Reduction and Failure to Obtain Secure Fixation. This double crime was perpetrated on three patients. In these cases, collapse of the fracture reduction occurred ten days to three weeks after an anteriorly tilted head had been secured with a nail which was too short.

Failure to Use a Smith-Petersen Nail or Other Similar Mechanically Suitable Equipment. In two patients, the use of four Moore pins did not prevent malunion of the fracture fragments. In two others, a Lorenzo screw combination failed to hold the fracture well enough to permit union. In these four patients, satisfactory reduction of type II or III fractures had been achieved and deep penetration of the head was obtained. In two of these, renailing efforts with a larger Boehler type nail and a Moore pin had not been sufficient to bring about healing. Another failure was thought to be due to imperfect penetration of the head fragment by a Madeira bolt; several weeks of additional splinting in a spica cast also was in vain. In two others, no internal fixation had been used in what were thought to be stable, impacted fractures.

Apparent Failure of the Bone of the Head Fragment to Withstand Stresses Placed upon It

Either from Intrinsic or Extrinsic Causes. Two patients had generalized osteoporosis which caused the nail to cut through the head fragment with resultant non-union and necrosis. Ideal reduction and fixation had been achieved in one of these patients; in the other, some degree of varus had been accepted in the original reduction and a shorter nail had been substituted for an originally placed nail which was too long. The cause of failure in two cases was thought to be due to weight-bearing too early in Pauwel's type II or III fractures by forgetful and senile patients. This complication developed in spite of excellent reduction and fixation.

Failure Due to "Backing Out" of the Nail. Because of argument among authorities about how often failures are due to backing out of the nail, we attempted to isolate cases in which this complication preceded disruption of the fracture site. Ten instances were found. In three, backing out of the nail occurred in the first seven weeks after fixation. In one, the nail had been placed very low in the inferior aspect of the head of the femur; in another, the nail had not been placed deeply enough. Inaccurate reduction with residual tilt of the head had been accepted in two instances, and backing out of the nail had occurred in spite of apparently secure and deep fixation of the head of the femur. In none of these cases had there been an instance of replacement of a longer by a shorter nail which might explain the tendency of the nail to back out of the head. In six cases, ideal reduction and nailing had not prevented backing out of the nail.

Non-union and Necrosis in Spite of Apparently Adequate Reduction and Secure Fixation. In twenty-eight patients, non-union and necrosis developed in spite of apparently adequate reduction and secure fixation in which there was no mechanical failure.

Necrosis in Spite of Union. In six patients, the development of necrosis after union of a subcapital fracture was the reason for performing secondary arthroplasty.

Insufficient Early Data Available for Evaluation. In seven patients, retrospect criticism could not be made because of the absence of early roentgenograms of the reduction and fixation.

TYPE OF PROSTHESIS USED

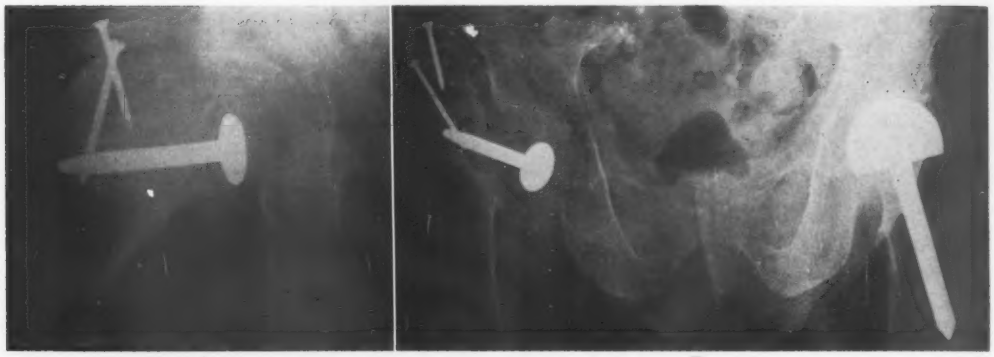
The various types of prosthetic replacements for the femoral head were used as follows: (1) Acrylic Judet prostheses were used in substitution six times primarily and secondarily in twenty-seven cases; (2) Vitallium® Judet prostheses were used six times primarily and on a secondary basis in nine instances; (3) Austin Moore prostheses were elected twenty-nine times primarily and secondarily in forty-three cases; and (4) Fred Thompson prostheses were selected for primary use in three cases and in secondary reconstruction in nine instances.

Experience has proved that the acrylic material of the early Judet prosthesis did not withstand prolonged usage and often became notched or fragmented with subsequent irritation of the hip joint. Although the more durable Vitallium Judet prosthesis, properly placed in a valgus position on femoral necks of adequate length, has given good results as a secondary replacement, a concomitant study by Drs. Philip D. Wilson, Jr. and Joseph B. Mason at The Hospital for Special Surgery states that this type of prosthesis has not proved to be an adequate support for primary replacement in fresh fractures of the femoral neck. Its use in such cases has often been followed by absorption of the neck support and insecure fixation. Furthermore, even in properly selected cases for secondary Judet arthroplasty, the technicalities demanded for optimum placement are intricate, and good results depend upon more tedious work than that required for good results with the use of the Austin Moore or Fred Thompson prosthesis. For these reasons, the Austin Moore stem prosthesis is generally used by practitioners on the New York Hospital-Hospital for Special Surgery Combined Fracture Service. (Fig. 3.)

SURGICAL APPROACH AND ITS RELATIONSHIP TO EARLY AMBULATION

The Gibson posterolateral approach and the Moore posterior approach have been used almost exclusively. We now prefer to reserve the posterior dislocation maneuver for use on recently fractured bones when the injury is not complicated by contractures of soft tissues. When this approach is used, postoperative treatment has not included measures to prevent dislocation, and early ambulation (in the first week or ten days after surgery) has been routinely permitted. Crutch support is only used when it is required for balance [6].

Early ambulation after anterior dislocation, in patients in whom part or all of the gluteus



3A 3B

FIG. 3. A, this eighty-two year old man received acrylic Judet prosthesis replacement primarily for an unstable, displaced subcapital fracture of his right hip, which is shown here soon after insertion. The placement of the prosthesis is not in valgus position. B, the patient received Vitallium Judet replacement arthroplasty after a displaced subcapital fracture in his left hip a year and a half later, and this has maintained good position for five years. The acrylic Judet prosthesis in the right hip, which was not inserted in valgus position, is noted to have become unstable. This complication developed within a year, and the patient has not been satisfied with the function of the right hip although he is well pleased with the left and has full active motion on this side.

minimus attachment had been left intact, has also been permitted without complication.

Osteotomy of the greater trochanter for anterior dislocation with reattachment by wires or screw fixation and the McFarland subperiosteal modification of the Gibson approach for anterior dislocation have usually been followed by postoperative protection in a spica cast, Wilkie boots, suspension or traction for three weeks. Sling suspension is used for an additional week before gradual ambulation in the therapeutic pool.

OPERATIVE AND POSTOPERATIVE COMPLICATIONS

Fracture of the Femur. Fractures of the femoral shaft were an operative complication in four cases. In one of these, splitting of the upper femur occurred at the time of insertion of the prosthesis and resulted in a loose fit. The use of Parham bands and postoperative spica cast splinting for six weeks was followed by a satisfactory functional result. In another instance a spica cast was used alone, and an unsatisfactory rating was given because of pain, although the patient had excellent motion and walked with only a cane for support. In both these cases, absorption occurred around the prosthesis and a high relative prominence of the greater trochanter with a Trendelenburg type of limp was observed. In another case, an oblique fracture of the shaft occurred at the tip of the stem when reduction of the prosthesis into the hip joint was attempted. Parham bands and bone grafts were used at the fracture site and the patient spent six months in a spica cast, but this did not bring about union. An extraordinarily long-stemmed Austin Moore prosthesis was designed by Dr. Wade and made by Austenal Laboratories for this patient. Prompt healing and excellent function followed its application. This type of prosthesis, with a long intramedullary stem, is advocated as primary treatment for this complication.

When fracture of the femoral shaft at the tip of the prosthetic stem occurred in reduction efforts in another patient, the operator elected to remove the prosthesis and leave the hip floating. Although she was free of pain, this patient did not have a good functional result because she could not manage crutches well.

Spinning of the Prosthesis. Austin Moore replacement was attempted through a posterior approach eight months after one patient had fractured his hip. A relaxed exposure was very difficult to obtain, and the prosthesis was repeatedly spun in its seat in an effort to bring about reduction of the hip. The prosthesis finally had to be secured by bone grafts. Postoperative alignment appeared to be satisfactory and absorption around the prosthesis has not developed after eighteen months; however, motion is so limited as to make the result unsatisfactory, even though the patient is ambulatory with crutches and has minimal pain.

Protrusio Acetabuli. We observed only one instance of absorption of the acetabulum with threatened protrusion into the pelvis by the prosthesis. This patient, who had been treated at another hospital, is not regarded as significant to this series because of her extraordinary history of having suffered a femoral neck fracture at the age of eighteen. She had also undergone a previous osteotomy. The only roentgenograms available for study had been taken three years after replacement of the femoral head and showed the stem of the prosthesis to be protruding down and out through the old nail track. In spite of the protrusio acetabuli and the unusual placement of the prosthesis, this patient had an excellent functional result three and a half years after replacement arthroplasty with almost completely normal motion, only slight pain and only occasional need for a cane.

Sciatic Palsy. There were three instances of operative complications of injury to the sciatic nerve. Two showed peroneal involvement and one a totally sciatic distribution. All made a complete recovery.

Infection. There were five instances of postoperative infection. In two, the infection was superficial and responded to incision and drainage. Another finally responded to prolonged deep incision drainage and administration of antibiotics. This complication did not interfere with a satisfactory result. Exacerbation of a previous infection, which had followed the original nailing treatment eighteen months before arthroplasty, was seen in one patient. A good result followed incision, drainage and the administration of antibiotics. In the fifth case, the end result of the infection cannot be reported due to lack of information.

None of the patients in whom these infections developed received antibiotics postoperatively on a prophylactic basis. In fact, of the entire group of 132 cases, fifty-five patients did not receive prophylactic treatment with antibiotics. The use of antibiotics as a preventive measure, which was ordered routinely in the early cases, is gradually being discontinued; however, there are occasional instances of prolonged and difficult surgery in which topical irrigations of the wound with antibiotic solutions also have been used before closure.

Dislocation. Dislocations of the prosthesis occurred postoperatively in four cases, all early in our experience and all with the Judet prosthesis. Each was reduced without surgical intervention and did not recur or contribute unfavorably, so far as could be determined, to the evaluation of the end result.

Other Postoperative Complications. The other postoperative complications which occurred were peroneal palsy, two cases; decubitus ulcers, five; aseptic necrosis of the skin at the operative site, three; infections of the urinary tract, two; paralytic ileus, one; thrombophlebitis, one; gastric hemorrhage necessitating gastrectomy on the twelfth postoperative day, one; homologous serum jaundice, one; severe senile psychoses, two; and gradually developing paraplegia, two.

MORTALITY

In the postoperative hospitalization period there were only three deaths among the entire group of 132 patients who received prosthetic replacement arthroplasty. Two deaths occurred in eighty-eight year old women and were thought to be due to myocardial infarction. The other patient was a fifty-eight year old man in whom paralytic ileus developed which did not respond to treatment; cardiac arrhythmia had been noted also. Postmortem examination was not obtained in any of these patients. Therefore, the mortality rate, was only 2.2 per cent among the 132 operations for replacement of the femoral head.

FOLLOW-UP STUDY

The number and percentage of patients available for follow-up study of six months or more were as follows: over-all, 103 of 132 (78 per cent); primary, twenty-seven of forty-four (63.6 per cent); and secondary, seventy-three of eighty-eight (82.9 per cent).

The average length of follow-up in this series was as follows: over-all, two years, six months (from six to ninety-six months); primary, two years (from six to seventy-two months); and secondary, two years, eight months (from six to ninety-six months).

END RESULTS

The results of therapy were analyzed in relation to motion, pain and support required in ambulation. The number of satisfactory results were determined on a qualitative rather than a quantitative basis (including a status of relatively little pain in a patient with sufficient motion to reach his foot to put on his own shoe, as well as sufficient balance to get around reasonably well with or without support). An

TABLE I

Type of Prosthesis	Range of Motion		Pain				Support				Result	
	Good	Poor	None	Slight	Moderate	Severe	None	Cane	One or Two Crutches	Not Walking	Satisfactory	Poor
Primary:												
Acrylic Judet	2	3	1	0	2	2	0	3	2	0	2	3
Vitallium Judet	2	1	1	2	0	0	0	1	2	0	2	1
Fred Thompson or Austin Moore	20	2	11	7	2	2	4	12	4	2	19	3
Total	24	6	13	9	4	4	4	16	8	2	23	7
Secondary:												
Acrylic Judet	19	6	11	6	6	2	6	9	9	1	21	4
Vitallium Judet	5	1	3	1	1	1	0	4	2	0	4	2
Fred Thompson or Austin Moore	38	4	18	16	6	2	11	19	11	1	40	2
Total	62	11	32	23	13	5	17	32	22	2	65	8
Combined total:												
Judet	28	11	16	9	9	5	6	17	15	3	29	10
Moore-Thompson	58	6	29	23	8	4	15	31	15	1	59	5

additional criterion was that a patient who was being rated after a secondary prosthetic replacement should be significantly improved as a result of this operation. We have related the preceding criteria to 103 patients in Table I.

Satisfactory Results. Among the patients who received primary replacement arthroplasties, there were satisfactory results in two of five with acrylic Judet replacements, two of three with Vitallium Judet substitutions, and nineteen of twenty-two in whom the Fred Thompson or Austin Moore prosthesis was used. Thus, of all the primary replacements considered, satisfactory results were obtained in twenty-three of thirty cases.

Among the patients who had secondary arthroplasties, satisfactory results were obtained with the acrylic Judet prosthesis in twenty-one of twenty-five cases, with the Vitallium Judet prosthesis in four of six patients, and with the Fred Thompson or Austin Moore prosthesis in forty of forty-two cases. Thus with secondary replacement arthroplasty, all types considered together, success was obtained in sixty-five of seventy-three patients.

Unsatisfactory Results. There was a 25 per cent incidence (ten of thirty-nine) of poor results following the use of the Judet prosthesis in both primary and secondary replacements combined, and only an 8 per cent incidence (five of sixty-four) of poor results with the use of the Austin Moore or Fred Thompson prosthesis.

ANALYSIS OF POOR RESULTS

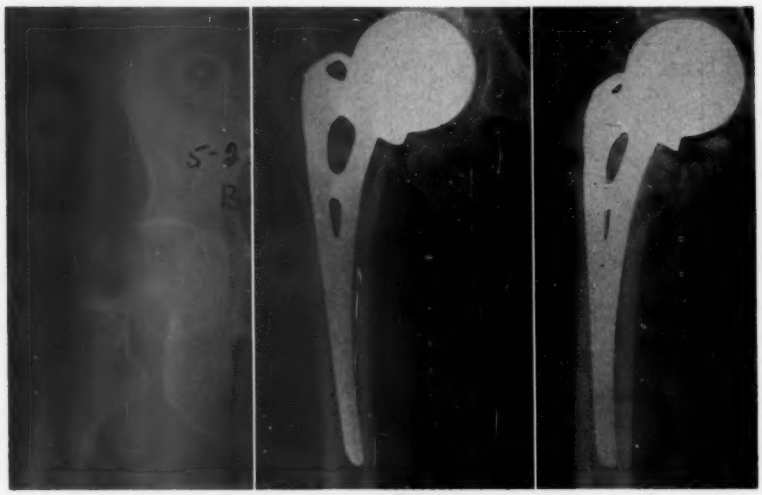
Primary Acrylic Judet Prosthesis. After primary use of the acrylic Judet prosthesis, one patient had pain and limitation of motion with development of varus and absorption around the stem. One patient had pain and varus without erosion or absorption, and another had pain, despite good alignment, without erosion or absorption.

Primary Vitallium Judet Prosthesis. Following primary use of the Vitallium Judet prosthesis, one patient had pain which was caused by absorption under the prosthesis.

Secondary Acrylic Judet Prosthesis. Following secondary use of the acrylic Judet prosthesis, one patient had pain with increasing varus; one had pain and limited motion with erosion of the superior outer acetabulum requiring removal of the prosthesis, and two had pain without notable roentgenographic changes.

Secondary Vitallium Judet Prosthesis. After secondary use of the Vitallium Judet prosthesis, one patient experienced severe pain and another had an extremely poor range of motion without explanatory roentgenographic changes.

Primary Moore or Thompson Prosthesis. Following primary use of the Austin Moore or Fred Thompson prosthesis, two patients had pain and limited motion associated with marked soft tissue calcification. One of these patients had a very comminuted fracture.



4A 4B 4C

FIG. 4. A, May 23, 1955. This sixty-seven year old man had such severe comminution of the neck of the femur that he was treated by primary Austin Moore replacement of the femoral head. B, June 8, 1955. Early postoperative appearance of the upper femur showed satisfactory seating of the prosthesis. C, January 24, 1956. However, six months later extensive calcification was noted in the capsule. Four-year follow-up examination disclosed considerable limitation of motion in this hip. The patient complained of a great deal of pain and required crutches even for restricted ambulation. Without absorption around the prosthesis, this poor result was thought due to calcification in the capsule which probably developed from the extensive comminution of the neck fracture.

(Fig. 4.) One had pain with absorption under the prosthesis (as previously described under "Complications") when deep settling of the prosthesis in the femur occurred after infraction of the calcar area of the base of the neck at the time of its insertion through a Smith-Petersen approach. (Fig. 5.)

Secondary Moore or Thompson Prostbesis. After the secondary use of a Moore or Thompson prosthesis, one patient (previously described under "Complications") had severe limitation of motion following an unstable placement of the prosthesis and difficult surgery through a posterior exposure. Another patient had pain and limited motion because of incomplete removal of the femoral head. The previously mentioned case, in which the prosthesis was removed after fracture of the femur at the base of the stem, is not included in the series of study for follow-up tolerance of the prosthesis.

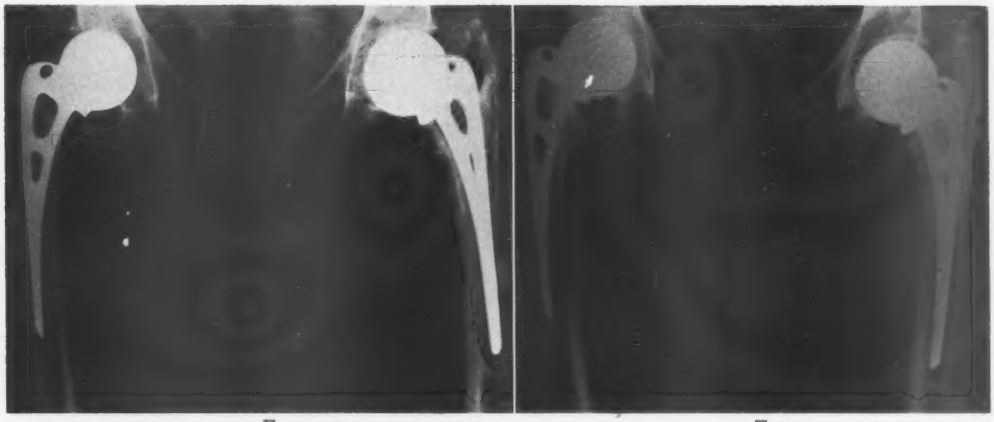
SUMMARY

In both primary and secondary replacement arthroplasty for subcapital fractures of the femur, the mortality rate which we observed has been almost three times less than any reported in the literature for a similar large group of subcapital fractures which were treated by reduction and internal fixation. We realize that this mortality rate may be lower than will occur in the future, because many of these patients received prosthetic arthroplasty primarily in deference to their poor general condition and probable inability to benefit from reduction and internal fixation of subcapital fractures.

Including postoperative complications, our end results have been twice as good with the Judet prosthesis and six times as good with the Moore-Thompson type replacement as those reported in several large studies of subcapital fractures treated by reduction and internal fixation in which the incidence of non-union and necrosis, early or late, has been about 50 per cent.

Therefore, we are encouraged to expand the use of primary replacement of the femoral head in the more severe types of subcapital fractures, and to lower the age candidacy to include

5A 5B 5C 5D



5E 5F

FIG. 5. A, this seventy-six year old man received primary Austin Moore replacement arthroplasty for the displaced, unstable subcapital fracture noted above after initial attempts at closed reduction and then open reduction had been unsuccessful. B, September 26, 1955. Close inspection of the area of the calcar just above the lesser trochanter suggests an area of infraction, which was thought to have been an operative complication during the insertion of the prosthesis through a Smith-Petersen approach. C, January 18, 1957. Some securement by reactive bone appeared to develop in the region of the calcar under the prosthesis, but early motion of the prosthesis had occurred in the upper femur as shown by absorption around the stem. D, two years later the patient fractured the opposite hip in an unstable displacement of the subcapital region. Smith-Petersen nailing was done, but removed within two months. E, October 18, 1957. Austin Moore replacement arthroplasty on a secondary basis was then carried out for this hip through a posterior approach. F, September 10, 1959. Four years after the prosthesis of the left hip had been inserted and two years after the one on the right, the patient had an unsatisfactory repair of the left hip with pain and a marked Trendelenburg sign, although motion was almost normal; the right hip was asymptomatic with a negative Trendelenburg sign and full strength and motion. He could get about with one cane but preferred to stay in a wheelchair most of the time. The film above shows that sclerosis has occurred around the tip of the stem of the Austin Moore prosthesis on the right and in the calcar under its seat there, whereas on the left continued absorption of the calcar has developed under the loose stem of the prosthesis.

6A 6B 6C

FIG. 6. A, June 22, 1958. This seventy-nine year old woman suffered a displaced subcapital fracture ten days prior to admission to a hospital. She had been in good health. B, September 8, 1958. Primary replacement arthroplasty was carried out, and by the time this film was taken the patient was walking with full weight-bearing with one crutch. C, September 10, 1959. One year later the patient was examined and showed no Trendelenburg sign and excellent range of motion in the operated hip. She reported that she had little pain and could walk ten to twelve blocks a day. She occasionally used a cane but did not feel the need for it.

patients in the sixth decade of life. With the exception of late secondary replacement where abundant viable neck exists, we would not recommend the use of the Judet prosthesis. If the Judet type reconstruction is attempted, the Vitallium prosthesis should be used and only by those who are most experienced and skilled in the intricate and exact technicalities of its application.

Although we are encouraged by our findings (Fig. 6), we recognize the need for intensive investigation of all types of subcapital fractures in an effort to find improved methods for saving the femoral head and obtaining union by reduction and internal fixation. It is our hope that further investigation will define the indications for primary replacement of the femoral head in those cases which would be doomed to failure by efforts at reduction and fixation. Certainly no such criteria is presently available in the literature.

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Separation of the Lower Femoral Epiphysis

CHARLES S. NEER II, M.D., *New York, New York*

From the Department of Orthopaedic Surgery, College of Physicians and Surgeons, Columbia University; and the Fracture Service, New York Orthopaedic Hospital, Columbia-Presbyterian Medical Center, New York, New York.

Two years ago I was consulted regarding a fifteen year old football player with a marked displacement of the lower femoral epiphysis. Inadequacy of experience with this rare injury precipitated a review of the literature. This was quite unsatisfying.

Most reports had been based upon one or two examples. Rarely had growth been observed throughout development. The largest series [*1*] contained six well documented lesions. These facts led to conflicting opinions regarding the mechanism of injury, the pathology and the prognosis. While it was generally accepted that the lower femoral epiphysis is the most actively growing of epiphyses, contributing 70 per cent of the length of the femur and 40 per cent of that of the lower extremity, there was great difference of opinion regarding the effect of trauma upon it. Some surgeons believed that alteration in growth following these fractures was exceptionally rare [*2,3*]. Others thought it to be quite common [*1,4,6*] and estimates ran as high as 95 per cent [*7*]. The need for re-evaluating these lesions was suggested further by the logic that, with the passage of the cartwheel, the classic mechanism of injury and pathology might not apply in modern times.

TABLE I
INCIDENCE OF EPIPHYSEAL FRACTURES, 1930–1955

	No. of Cases
Lower radius	1,096
Lower humerus	332
Lower fibula	302
Lower tibia	238
Lower ulna	136
Upper radius	124
Upper humerus	72
Lower femur*	28
Upper ulna	21
Upper tibia	17
Upper fibula	2
Total	2,368

* Seven cases which were diagnosed clinically but lacked roentgenographic proof were excluded from the study.

STUDY

This paper presents twenty-one fractures with displacement of the epiphysis treated at the New York Orthopaedic Hospital–Columbia-Presbyterian Medical Center between the years 1930 and 1955. Seven additional lesions, diagnosed as epiphyseal fractures but lacking positive roentgenographic proof, were excluded. Separation of the lower femoral epiphysis comprises 1 per cent of epiphyseal injuries. (Table I.) Eighteen of the twenty-one patients were males. Their ages ranged from birth to sixteen years. Eleven fractures occurred in the left femur and ten in the right. Follow-up examinations throughout the re-

TABLE II
MECHANISM OF INJURY IN TWENTY-ONE PATIENTS

Mechanism		No. of Patients
Force *above* epiphysis		15
Hit by car	9	
Football	3	
Hit by swing	2	
Kick by horse	1	
Force *upon* epiphysis		5
Fell	3	
Skiing	2	
Twisting force		1
Caught leg in bench	1	

FIG. 1. Typical displacement. The epiphysis is lateral and the shaft fragment is beneath the skin medially.

maining growth of the bone was possible in sixteen patients.

RESULTS

The usual mechanism of injury (Table II), producing fifteen of the twenty-one fractures, was a severe direct blow upon the lateral side of the femur just above the epiphysis while the foot was fixed upon the ground, e.g., hit by an automobile or in football. (Fig. 1.) In five patients the blow landed upon the knee (below the epiphyseal line) resulting in medial or posteromedial displacement. Anterior displacement of the epiphysis due to hyperextension twisting force, resembling that which a cartwheel might produce, and ascribed as characteristic, was seen in only one patient.

Treatment consisted of plaster immobilization for varying periods from twenty-two days to eight weeks. Three and a half weeks' immobilization proved adequate. Closed reduction was usually stable. (Fig. 2.) Two fractures were unstable, however, and in these the diaphysis slipped medially producing necrosis of the overlying skin. (Fig. 3.) In one of the unfortunate patients with this complication a severe infection developed. Circulatory embarrassment from popliteal pressure was found in one patient, and this was relieved promptly by reduction of the fracture. Non-weight–bearing ambulation on crutches was enforced for a period of two months, as a rule.

Clinical and roentgenographic follow-up examinations until closure of the epiphysis were accomplished in sixteen patients. Their

FIG. 2. Reduction is usually stable because of the concave surfaces of the epiphysis.

FIG. 3. Unstable lesions are seen which may produce pressure necrosis of the skin medially unless held in proper alignment by more secure fixation than plaster alone.

TABLE III
LENGTH OF FOLLOW-UP EXAMINATION IN TWENTY-ONE PATIENTS

	No. of Patients
Insufficient	4
2–3 yr.	2
3–5 yr.	5
5–8 yr.	5
8–11 yr.	4
Over 11 yr.	1

results and that of one eight-year follow-up were analyzed. (Table III.) In ten patients there was no alteration in length. (Table IV.) It should be noted that the fractures in these patients were only mildly displaced and that reduction was considered necessary in only one instance. This was in an older patient nearing time for epiphyseal closure. It might be mentioned that none of the "epiphyseal injuries without displacement" (excluded from the study) were followed by growth change. Shortening of the extremity due to premature closure of the epiphysis occurred in seven patients (42 per cent). (Table V.) The majority of these fractures were displaced sufficiently to require reduction. Furthermore, the ages of these patients tended away from the extremes, e.g., not in the very young or in the older children. The epiphysis was closed within one year of the injury in three patients. However, of particular interest was the finding of deceleration of growth and shortening due to late premature closure of the epiphysis seen in four other patients. (Fig. 4 and Table V.) In a number of the patients listed in Table IV, the in-

TABLE V
GROWTH DISTURBANCE (SEVEN OF SEVENTEEN PATIENTS)

Age of Patient	Reduction	Length of Follow-Up Examination (yr.)	Shortening (cm.)
7 yr., 2 mo.	Yes	7	1.5
7 yr., 10 mo.	Yes	10	2.0
10 yr.	No	6	0.5
13 yr., 6 mo.	No	2	2.0
13 yr., 10 mo.	Yes	4	1.0
13 yr., 10 mo.	Yes	4	3.5
15 yr.	Yes	5	1.5

TABLE IV
GROWTH NORMAL (TEN OF SEVENTEEN PATIENTS)

Age of Patient	Reduction	Length of Follow-Up Examination (yr.)
11 mo.	No	8
4 yr., 2 mo.	No	10
8 yr.	No	6
9 yr.	No	13
11 yr., 4 mo.	No	7
12 yr.	No	8
14 yr., 4 mo.	No	2
14 yr., 7 mo.	No	3
15 yr.	No	4
15 yr., 6 mo.	Yes	2

FIG. 4. Deceleration of growth of the epiphysis and late premature closure. *Left*, the injury in a seven year, ten month old patient. *Right*, seven years later note that the left epiphysis has closed. Leg length discrepancy of 2.0 cm. resulted.

FIG. 5. Valgus and varus deformities of 20 degrees tend to correct spontaneously if three years' growth remains. *Left*, position of healing. *Right*, five years later. The only trace of deformity is the irregularity at the medial epicondyle.

jured epiphysis closed before the uninjured one but with no detectable shortening resulting.

Valgus and varus deformities of up to 20 degrees tended to correct spontaneously provided three years' growth remained. (Fig. 5.) Detectable residual mal-alignment was seen in only one patient.

COMMENTS

Longitudinal growth of bone is dependent upon the proliferating cartilage cells at the epiphyseal line, with the exception of the small contribution made by ossification of the center itself. It is well known that these proliferating columns may be damaged by a crushing injury resulting in immediate closure of the epiphysis. Ollier [*8*] thought that when epiphyseal fractures occurred which were not complicated by growth change the fracture had passed through the juxtaepiphyseal new bone just adjacent to the cartilage without damaging the proliferating zone. This is undoubtedly true. It has, however, been further established that interference with the blood supply of the epiphysis may also produce growth change [*9*]. This does not usually cause immediate closure of the growth line [*10*]. The instances of late premature closure of the ossification centers seen in this study are presumably based upon injury to blood supply and nutrition rather than crushing and immediate death of the proliferating cells. The greater the displacement of the fragments, the more apt early closure was to occur. In this series the maximum shortening produced by the deceleration process was 2.0 cm. It is, nevertheless, of interest and importance in the lower femoral epiphyseal injuries, because of this delayed slowing of growth, to continue follow-up examinations until the actual closure of the epiphysis has occurred. Observations for two or three years are often inadequate. This late "deceleration of growth" phenomenon is more pronounced in the lower femur than elsewhere simply because more growth is contributed by this epiphysis so that the effect is magnified.

CONCLUSIONS

1. The modern "cartwheel fracture" (separation of the lower femoral epiphysis) is usually produced by a severe blow to the lateral side of the thigh just above the epiphyseal line.

2. In the typical displacement, the epiphysis is lateral rather than anterior.

3. The incidence of growth change based upon follow-up examinations throughout the remaining life of the epiphysis was 42 per cent, the prognosis being poorer when there has been marked displacement or when the child is twelve to thirteen years of age.

4. Deceleration of growth and late premature closure of the epiphysis is a frequent complication, and this resulted in measurable shortening in four patients. This phenomenon is magnified peculiarly in lower femoral epiphyseal injuries because of the greater growth activity of this ossification center.

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DISCUSSION OF PAPERS BY DRS. CAMPBELL, MASON, WILSON AND WADE; AND NEER

Sir Reginald Watson-Jones (London, Eng.): I went through a phase of using primary prosthetic replacement for femoral fractures in particularly elderly patients and I abandoned it, because even with the best replacement the results are not as good. In two-thirds of the replacements good results can be obtained from femoral neck nailing provided we recognize that reduction of these fractures should be done with a velvet hand and abandon all senseless manipulating. With the gentlest touch these fractures simply need placing in neutral rotation and slight reduction, provided also that we put the nail precisely down the middle of the

neck and head in the position where it is less likely to endanger blood vessels.

Since two-thirds of the patients can secure good results from the very minimum operative procedure of nailing (which only takes ten minutes' operating time) no one is going to tell me that this is as great a risk as a complete Smith-Petersen approach. In the other one-third of patients with accurate nailing, in whom a crumbling head develops one, two or three years later, by all means use the Austin Moore prosthesis.

There have been three fallacies about avascular necrosis; I am responsible for one of them, Phemister is responsible for the second and all of us have been responsible for the third.

I insisted long ago that avascular necrosis of bone was shown by relative density. Phemister said that it undergoes creeping substitution. It is not that it is a running, indeed, a galloping substitution; it usually starts within a few days and although all the bone cells are empty, it is dead bone; the marrow cells, if they do not survive from the beginning, very quickly regenerate and immediately osteoid is laid down and new bone on the surface of the dead trabeculae is removed. Almost simultaneously there is regeneration, and that, I think, explains the fallacy for which I was responsible. It is not alone a relative density. There is relative density to the other bones around which were allowed to become porotic. However, in addition, the dead bone which cannot lose its calcium has opposed on the surface new bone which loses more calcium. Thus there is relative density. Avascular necrosis of bone necessarily means degenerated, fragmented, crushed or ruined bone; I think that explains this very sharp discrepancy in percentages in various reports, some saying 10 per cent and others ranging up to 70 per cent. Those figures relate to the disasters of bone which has lost its blood supply, and I am certain they are not an accurate record of the percentages of cases which have lost their blood supply. There are many injuries in which bone has lost its blood supply, and the bone regenerates perfectly without any permanent disability. For this reason I still hold to a conservative approach, despite avascular necrosis.

O. P. Hampton, Jr. (St. Louis, Mo.): Dr. Neer's paper makes us most cognizant of long term follow-up examinations of growth after epiphyseal separation.

I want to apologize to Sir Reginald Watson-Jones. In St. Louis we believe there are indications for primary femoral head prosthetic implantation. If the patient is physiologically seventy-five years old or older (and I have not forgotten what Sir Reginald said to me about these people deserving rest), he probably will not withstand the rigors of three or four months or more of non-weight-bearing and relative inactivity and then be able to undergo a second operation. If we appraise them as such, we believe that primary femoral head replacement using the Fred Thompson or Austin Moore type of prosthesis is a good procedure. It restores ambulation within a matter of days, not a matter of months and years.

T. B. Quigley (Boston, Mass.): With regard to subcapital fractures of the femoral neck in the aged, we share Dr. Hampton's point of view. Here I respectfully take issue with Sir. Reginald Watson-Jones. I am sure he will agree that it is most gratifying to watch a woman in the ninth decade of life *walk* out of the hospital three or four weeks after her fracture.

Dr. Neer's excellent paper brings up the matter of the forces which produce this injury. Torsion is important, but probably abduction of the tibia on the femur is most often dominant. In teen-aged patients the weak link is the distal femoral epiphysis. During the next few decades it is the medial and anterior cruciate ligaments, and from then on it is, of course, the lateral tibial plateau.

It is the duty of the members of this Association to spread the word that these injuries must be very promptly recognized and treated if amputations are to be avoided.

C. O. Carothers (Cincinnati, Ohio): In Cincinnati we have been using in the hospital the Gaenslen prosthesis, which is a large modified Smith-Petersen cup with a flange permitting the fixation of the cup to the pelvis by three screws. We have used this in eighteen patients, some of whom have been followed up for several years. Of the first five, three have excellent motion and the other two have an amount of metaplastic ossification which is fantastic; I noted Dr. Wade had some.

As far as the use of prostheses in fresh fractures of the femur is concerned, several years ago I discussed at this meeting our series (to that time) of 105 fresh fractures, and our statistics were remarkably similar to those currently presented. We had four infections and four dislocations. I think it is an excellent procedure. We are very careful to use the posterior approach, dividing the short external rotators and leaving the gluteus intact. I like to see the patients walking within the first week.

Dr. Neer's paper was interesting to me because I worked on the same problem at the ankle and presented it here a few years ago. There are a few points, I think, that are worthwhile mentioning. The most important is that we found the valgus deformity tended to correct spontaneously. This concept dated back to Heuter in 1863, yet I was taught that it was very unlikely that angular deformity would correct. Dr. Neer has found even a greater tendency toward this spontaneous correction. I believe it is something to think about.

I would like to ask Dr. Neer whether the slowing down of growth in his series could have been due to the direct trauma. I noted he had five cases of direct trauma and seven cases of shortening.

PRESTON A. WADE (New York, N.Y.): Primary femoral head replacements are not routine in our hospital by any means. If we only knew which ones would heal and which ones would not, we would then have little difficulty in choosing the proper procedure. At present we believe that in most instances the patient deserves a simple nailing first.

Primary prosthetic replacement has complications. We treated one fracture of the shaft of the femur below the stem of the prosthesis in a patient in whom the bone was very fragile. This patient was in a spica for a year and the fracture did not heal. Therefore, we devised a long-stemmed prosthesis and replaced the original prosthesis with it. The fracture healed and the patient is back at work.

R. D. CAMPBELL, JR. (closing): I want to reemphasize Dr. Wade's remarks that the indications for using primary prostheses were not intended to include impacted fractures even in the elderly. I have not been able to find a good report of a large series which defines which fractures heal and which do not, in regard to type 2 or type 3 displaced fractures. I heard a paper in Boston three years ago in which the essayist stated he had reviewed at that time twenty-five displaced type 3 subcapital fractures and had not found one that healed. Massie reported healing in fifty of fifty-six patients treated by his method of full internal rotation and medial replacement of the shaft, but did not define the types of fractures treated. It was tempting in this study to get lost in an analysis of the cases which came to secondary replacement. In retrospect criticism of the treatment of these, reduction of fixation seemed imperfect in one-half. We recognize, however, that many others similarly treated may have gone on to success, and we plan to make a further study of this problem.

C. S. NEER (closing): In answer to Dr. Carothers' question, we could find no correlation of the mechanism of injury to the incidence of growth disturbance. The correlation was rather between the amount of displacement of the fracture and the age of the patient at the time the fracture occurred.

I would like to add a word with regard to hip replacement prosthesis. The mortality rate in our Clinic has been very much higher than that reported here. This has been the experience in most other parts of the country. The reason for the high mortality rate is that we perform immediate replacement for the patient and not for the fracture. We utilize this procedure only when the life expectancy of the patient is not greater than three or four years or when the patient's physical activities have been sufficiently curtailed by concomitant problems so that they could not utilize a better hip. This is done with the knowledge that a superior hip would have been obtained had we achieved bone union. We cannot accurately predict, on the basis of the initial roentgenographic appearance of the fracture, whether union can be obtained and the head survive and, therefore, strive for bone union in all patients except those with a short expectancy or severe physical handicap. On this basis, the related mortality rate following replacement prosthesis was 20 per cent, indicating that although prosthesis has a valuable place, it is not an innocuous procedure for a poor risk, fragile patient. Therefore, we believe that there is, in addition, a place for simple blind nailing or insertion of a heavy Steinmann pin to control pain in selected patients who are extremely poor risks, rather than subjecting them to the greater operation of insertion of a prosthesis.

Circumferential Freeze-Dried and Frozen Bone Homografts Fixed with an Intramedullary Nail to the Femoral Shaft of the Dog

BROOKE ROBERTS, M.D., WILLIAM T. FITTS, JR., M.D., SIMON M. K. MYINT, M.D., JACQUES JENNY, V.D.M., HERNDON B. LEHR, M.D., LEWIS ANDERSON, M.D. AND T. HUNTER PRYOR, M.D., *Philadelphia, Pennsylvania*

From the Department of Surgery, Hospital of the University of Pennsylvania and the Harrison Department of Surgical Research, Schools of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania. Supported by contract No. DA-43-007-MD-489 between the Office of the Surgeon General, U. S. Army and the University of Pennsylvania.

THE destruction of bone by trauma, neoplasm or infection often necessitates the repair of large bony defects. We have previously reported [1] on fresh circumferential homografts and autografts, fixed with an intramedullary nail to replace defects in the femoral shaft of the dog. The homografts proved to be as successful as the autografts. When a technic was developed that solidly fixed the graft to the host fragments, both homografts and autografts were successful in about 75 per cent of the cases.

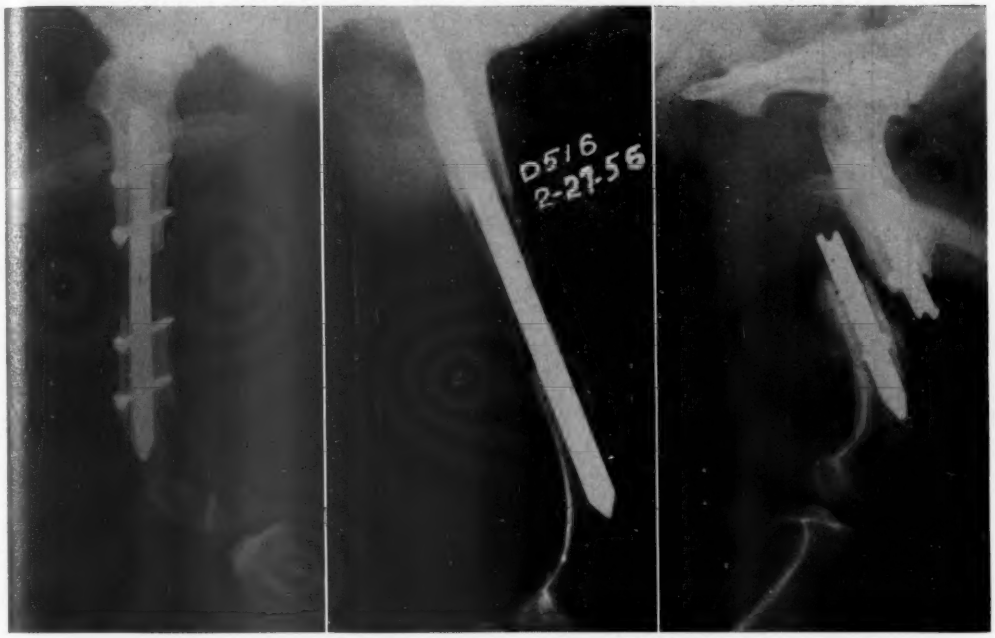
The practical advantages of securing, storing and transporting freeze-dried and frozen bone are apparent, especially in military surgery. The experiments reported herein were performed to determine if freeze-dried and frozen bone homografts would function as well as fresh bone homografts and to determine if union would occur if no grafts were used to fill the defect created in these experiments, a question previously raised by Dr. Paul Magnuson of Chicago.

METHODS

Mongrel dogs weighing 6 to 15 kg. were observed for a period of three weeks before being subjected to the experimental procedure. During this period each dog was given two 20 cc. injections of homologous anticanine distemper serum and a five-day course of oral sulfamerazine. After operation all dogs were given 100,000 units of penicillin intramuscularly for five consecutive days.

At the time of operation, segments of 1.5 to 2 cm. were removed from the middle of the femoral shaft by an electric bone saw. The defect was either (1) maintained by a Livingston nail (Fig. 1), (2) filled by a similar segment of homologous freeze-dried bone and fixed with a three-flanged intramedullary nail (Fig. 2) or (3) filled with a similar segment of homologous frozen bone and held with the same nail.

The freeze-dried bone grafts used in these experiments were obtained under sterile conditions from the femoral and tibial shafts of healthy mongrel dogs at the end of acute experiments in the laboratory. This bone was frozen by placing it in a compartment of dry ice at a temperature of −78°C., where it was stored until ready for freeze-drying. The frozen bone segments were put in wide mouthed test tubes and placed in the drying compartment of a freeze-dryer. An immediate vacuum was obtained and the bones were dried until a sample of bone did not lose weight when placed in a vacuum dessicator containing phosphorus pentoxide. Four lots of freeze-dried bone were used during the course of the experiments. The first lot was freeze-dried for two weeks at a pressure of 150 μ Hg. The remaining three lots were freeze-dried at separate times for seven days



1 2 3

FIG. 1. Roentgenogram taken immediately after operation. A gap has been created in the dog's femoral shaft by removal of a 2 cm. segment of bone, and has been maintained by insertion of a Livingston nail.

FIG. 2. Roentgenogram taken immediately after operation. The gap made in the femoral shaft has been filled with a freeze-dried femoral homograft, and fixed with a three flanged intramedullary nail.

FIG. 3. Roentgenogram taken four months after operation and showing breaking of the Livingston nail.

each at a pressure of less than 50 μ Hg, which proved to be sufficient time for the drying process. (The freeze-dryer will only accommodate fifteen tubes at a time, hence the separation into lots.) The samples from all four lots were sealed in glass tubes under vacuum and stored for one week to six months before being used. (The apparatus used for freeze-drying has been previously described [2].)

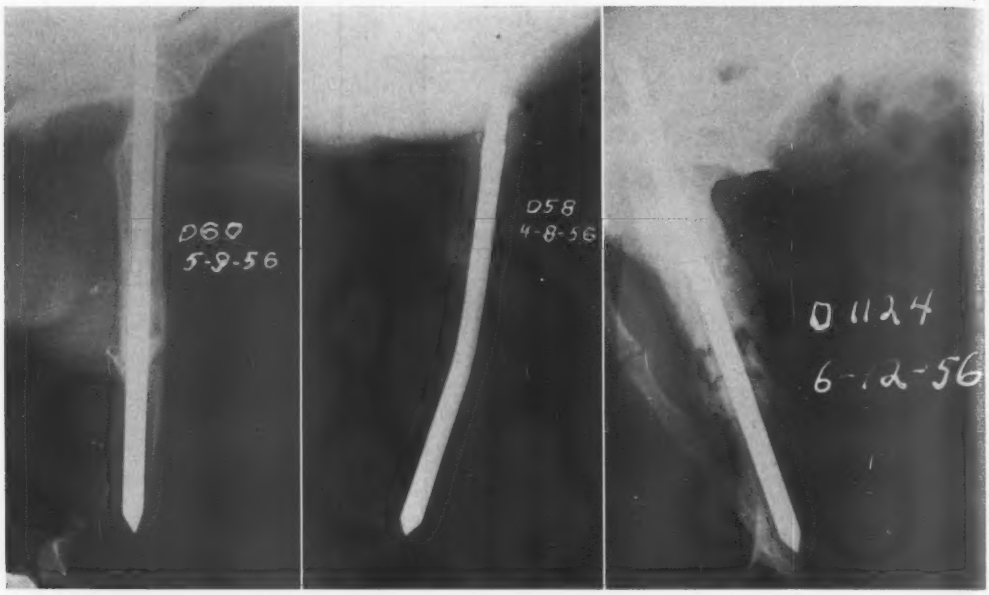
Frozen sections of bone were prepared in a similar manner. The sections were removed under sterile conditions from either the femoral or tibial shafts; they were not treated with antibiotics. The bone was placed in dry ice storage, cooled to $-78°$C. in about three or four minutes and stored for several weeks to six months before use.

In all experiments no external method of immobilization was applied after fixation of the graft and the dogs were allowed to bear weight as soon as they would. The healing process of the grafts was studied by clinical examination, roentgenographic examination at intervals, and gross and microscopic examination after death or sacrifice of the animals.

RESULTS

Gap Maintained with Livingston Nail. In nine dogs operated upon the gap was kept open by a Livingston nail. Bridging of the gap did not occur in any of these nine dogs. In six instances the Livingston nail broke approximately four months after operation (Fig. 3) without any evidence of union having occurred.

Freeze-Dried Homografts. Freeze-dried homografts were inserted into the defects in the femoral shafts of forty-four dogs. (Grafts from the first lot of freeze-dried grafts were inserted into ten dogs, from the second lot into fourteen dogs, from the third lot into twelve dogs, and from the fourth lot into eight dogs.) Of these forty-four hemografts, only thirteen (29 per cent) were complete successes with consolidation of the graft and maintenance of full bone length after the intramedullary nail was removed. (Fig. 4.)



4 5 6

FIG. 4. Roentgenogram taken five months after operation and showing healing of freeze-dried graft. Length has been maintained and the three flanged intramedullary nail has maintained its position. Length and position were maintained after removal of the nail.

FIG. 5. Roentgenogram taken three months after operation and showing beginning absorption of a freeze-dried graft and bending of the intramedullary nail.

FIG. 6. Roentgenogram taken three months after operation and showing beginning graft failure, which went on to complete absorption.

The freeze-dried homografts failed in seventeen cases (38 per cent). Of these failures, a significant per cent was due to splitting of the graft either at the time of insertion or soon afterwards, a problem we did not encounter when using fresh bone. Fourteen dogs (32 per cent) died either from infection or other disease unrelated directly to the grafting procedure before the outcome of the graft could be determined. Figure 5 shows a failure of a freeze-dried graft.

Frozen Bone Grafts. Frozen bone grafts were inserted into the femoral shafts of nine dogs. Two of these grafts were successful, five were failures, and two dogs died of infection before the results of the grafts could be determined. Figure 6 shows a failure of a frozen bone graft.

COMMENTS

It seems unlikely that a gap in a long bone as large as we created and maintained with the use of a Livingston nail can be closed without some form of graft. There may be better methods of fixation of the proximal and distal femoral shaft after the gap has been created but the fixation which was achieved seemed good. With the method used in these experiments, however, there was no attempt at bridging the artifically created gap in nine trials.

The technic of freeze-drying probably influences the results to some extent, but if all grafts are dried to a standard degree of dryness, the effect of variations and technic should be minimal. There seems to be no question that freeze-dried bone grafts can, under some circumstances, be successful. Under the conditions of these experiments freeze-dried bone was not as successful as fresh bone homografts. It must be realized that these bones are subjected to unusual stresses in comparison with most bone grafts in man. Because freeze-dried grafts did not heal as well as fresh homografts under the conditions of these experiments does not necessarily mean that freeze-dried bone grafts would not be as successful as fresh homografts

under conditions of less stress. We do not know if the tendency of our freeze-dried grafts to split is related to the method of freezing, drying, storing or to other factors. Changing the period of reconstitution of the graft in saline solution did not appear to influence the tendency of the freeze-dried bone to split.

In nine experiments frozen bone did not appear to be as successful as fresh homografts and was comparable to freeze-dried bone.

Because freeze-dried bone or frozen bone has such obvious advantages in stock-piling and procurement and could be used to great advantage under disaster conditions, we believe that further attempts should be made to determine why some of the freeze-dried grafts were successful and others failures. In our experiments with fresh bone homografts, mechanical factors and fixation of the graft in the host bones seem to be all important; therefore, we developed a technic in which the percentage of success was high when the mechanical factor of fixation was good. However, using this same technic we were not able to obtain similar results with either freeze-dried or frozen bone. Even when excellent stability of the graft and the host bone fragments was thought to be effected, many of the grafts failed to be reconstituted into the host bones.

CONCLUSION

Freeze-dried and frozen bone homografts were not as successful in our hands when used for grafts to fill a circumferential defect in the femoral shaft of dogs as were fresh grafts. When using freeze-dried bone, of forty-four grafts only thirteen were successful. When frozen bone was used for the graft only two of nine grafts were successful. In a control series of nine dogs in which the defect was maintained between the proximal and distal bone fragments by a Livingston nail, the gap was not bridged in any instance.

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Replacement of Bone Defects in Dogs by Experimental Soft Tissue Transplants

PRELIMINARY REPORT

MICHAEL SIERP, M.D., PAUL W. BRAUNSTEIN, M.D., WILLIAM SAMELLAS, M.D. AND JOHN W. DRAPER, M.D., *New York, New York*

From the Departments of Surgery and Urology, New York Hospital, Bellevue Hospital and Cornell University Medical College, New York, New York.

THE presence of a defect or bony gap at the site of a fracture presents a major problem in healing. Recently there have been some impressive reports concerning the use of polymers and "ostamers" to bridge new and long-standing bone defects. These agents are foreign bodies and, therefore, will probably have the usual undesirable features produced by foreign bodies in normal tissue.

Heterotopic bone formation in the urinary tract and in the soft tissues of the body following transplantation of uroepithelium has been reported by many investigators. Huggins [*1*] investigated this phenomenon extensively in 1931. Urist and McLean [*2*] investigated heterotopic bone formation in various tissues following transplantation to the anterior chamber of the eye. Levander [*3–5*] successfully produced osteogenesis in rabbit muscle by the application of an extract of various bone elements. Copher, Key and West [*6*] first demonstrated the healing of fractures by placing bladder epithelium in the vicinity of these fractures. Eskelund and Plum [*7*] studied the process involved in the healing of fractures in rats extensively and investigated the effects of various tissues and the extracts of tissues in the healing of fractures. He thought that the presence of a lecithin fraction was responsible for the accelerated healing of these fractures. Draper et al. [*8*], while studying an experimental operation for ureteropyeloneostomy in dogs, found bone formed in the submucosal tissue, and again corroborated evidence from previous operations that this was due to the change of the normally situated fibroblasts into osteoblasts. This process was observed microscopically within two weeks from the time of operation. Macroscopic bone developed at the site of anastomosis in animals studied for as long as three months. Microscopic examination of this tissue showed it to be normal bone.

Because of these findings, we decided to continue the study of the ability of this tissue to produce bone and stimulate callus formation. This study was undertaken to determine whether or not renal pelvic epithelium which had been transplanted to bone defects would lead to bone formation at an accelerated rate and in a larger quantity than would usually be expected in the laboratory dog.

METHOD OF STUDY

Mongrel dogs were selected at random and were anesthetized with intravenous Nembutal.® The kidney was exposed by a transabdominal incision. It was then isolated, and its pedicle was clamped with a Potts clamp. After twenty minutes of renal ischemia, the kidney was removed and the renal pelvis was stripped from the kidney. The renal-pelvic mucosa was then removed from the renal pelvis and placed in a sponge which was soaked in saline solution. The wound was closed in layers after the renal pedicle has been tied and transfixed. After closure of the abdominal wound, both forelegs were opened over the radius. The tendons overlying the radius were stripped in an identical manner bilaterally. Then, approximately 8 cm. above the distal radial prominence, a bone defect was created bilaterally in the radius using a Gigli saw. The amount of bone removed and the amount of periosteal stripping were of equal extent. After the re-

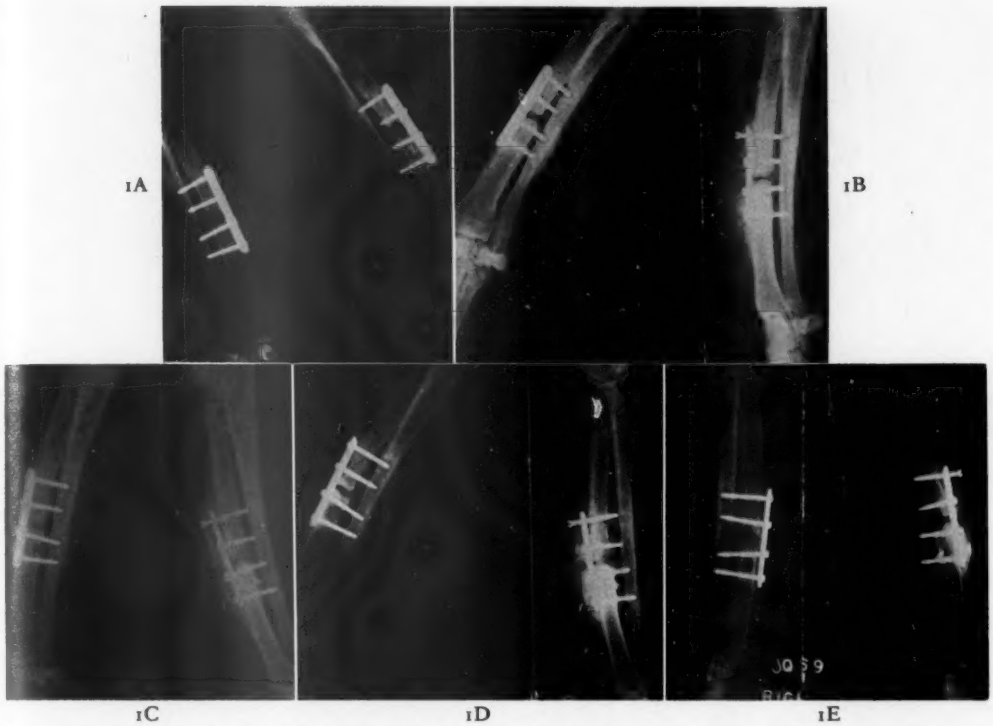


FIG. 1. Case 1. A, one month following renal pelvic transplant there is no obvious roentgenographic change, but clinically there was increased circumference of the site receiving the graft (left leg). B, at two months there is marked callus proliferation in the left foreleg. The obvious soft tissue thickening is demonstrated. C, at four months bone bridging has occurred, while there is still a visible defect in the control. D, at five months there is a striking difference in bony proliferation between the experimental and control side. E, at six months there is massive callus formation on the experimental side and minimal callus formation on the control side, although bony bridging has begun.

moval of this segment of bone, which was 5 mm. in length, the fragments were firmly fixed with a four-hole metal plate and four transfixion screws. A silver clip was then placed in the soft tissue of the leg to identify the site which had received the soft tissue transplant, and the mucosa was inserted in the defect. The wounds were closed in layers with silk sutures.

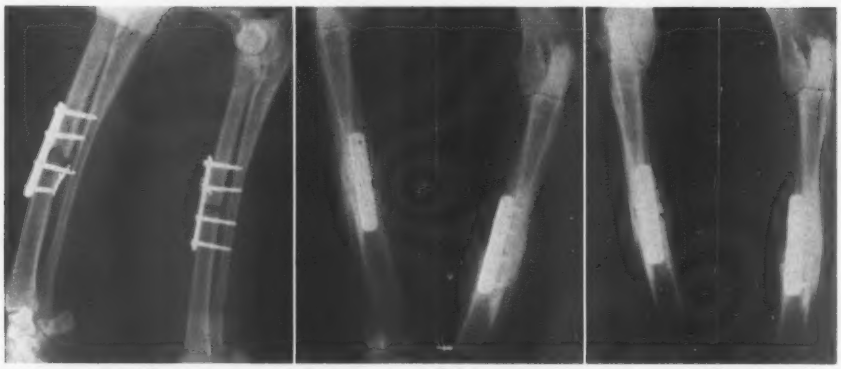
Gallbladder mucosa and urinary bladder mucosa were placed in surgically created bone defects in a similar manner.

RESULTS

When urinary bladder mucosa and gallbladder mucosa were transferred to a bone defect, there was some evidence of increased osteogenetic activity. (Table 1.) All but one of the six dogs with transplanted renal pelvic mucosa demonstrated a marked increase in osteogenetic activity as determined by the circumference of the treated leg compared to the control side. Roentgenograms showed evidence of increased callus formation and bone

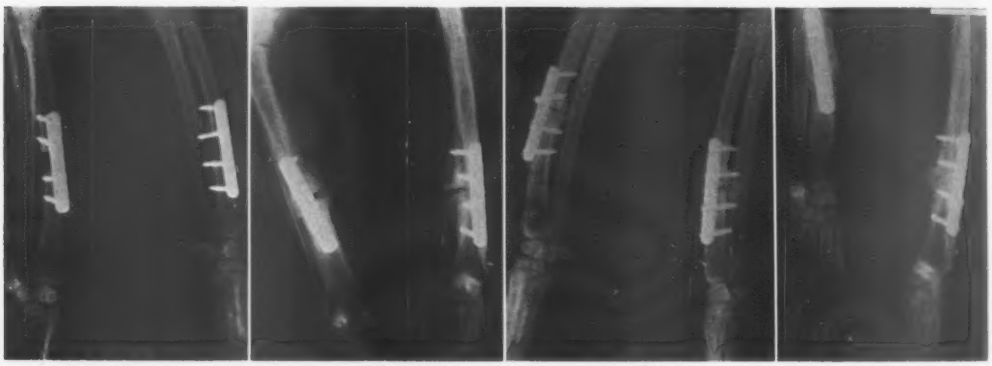
TABLE 1

Dog No.	Tissue Transplanted	Degree of Osteogenesis
838	Renal pelvic mucosa	+++
856	Renal pelvic mucosa	++++
869	Renal pelvic mucosa	++++
25	Renal pelvic mucosa	+
54	Renal pelvic mucosa	++++
917	Renal pelvic mucosa	++++
819	Urinary bladder mucosa	++
36	Gallbladder mucosa	−
15	Gallbladder mucosa	+



2A 2B 2C

FIG. 2. Case II. A, immediate postoperative films reveal the created bone defects with the urothelium transplanted in the left foreleg. B, at three months the side containing the uroepithelium transplant has developed massive callus and complete bone bridging. The control side exhibits moderate callus formation and bony bridging. C, at five months the increased callus is again noted and there still is incomplete bridging in the control side.



3A 3B 3C 3D

FIG. 3. Case III. A, postoperative film with urothelium transplant in the left foreleg (urinary bladder mucosa). B, at three months there is obvious increase in the callus in the left foreleg (site of transplant). C, healed soft tissue thickening is more marked on the transplant foreleg, but bony bridging is approximately equal at four months. D, at five months bony bridging occurred bilaterally. There is more callus on the experimental side.

bridging in the defect. This is well demonstrated in the following cases.

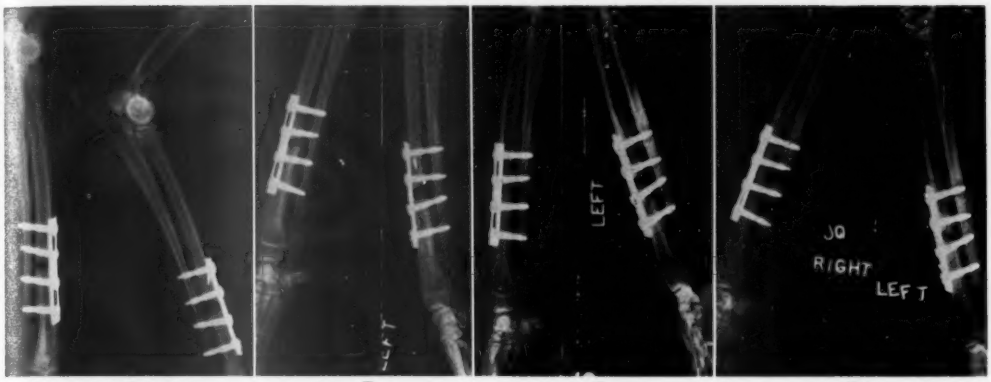
Cases I and II (Figs. 1 and 2) are examples of heterotopic bone formations caused by the implantation of renal uroepithelium in the bone defects. In each case, the forelegs marked by silver clips have received the epithelium transplant while the opposite leg is a control.

Case III (Fig. 3) represents a graft of urinary bladder mucosa to a bone defect. Increased osteogenesis has occurred but has not been equal to that exhibited by renal pelvic mucosal transplants.

Case IV (Fig. 4) represents the findings after the use of a transplant of gallbladder mucosa. The left foreleg received the mucosal transplant and the right was the control limb. After four months the control limb had healed while there was minimal, if any, difference in bone proliferation between the two limbs.

COMMENTS

While it has been known that transitional epithelium will lead to osteogenetic activity when transplanted to soft tissue in the same species, further studies of bone formation in bone defects have not been made generally



4A 4B 4C 4D

FIG. 4. Case IV. A, immediate postoperative film with created bone defect and gallbladder mucosa in left foreleg. B, at one month there is no callus formation bilaterally. C, at two months there is minimal callus formation of approximately equal amounts bilaterally. D, at four months the control side has bridged the bony gap while the experimental side has not demonstrated complete healing, although there may be a slight increase in bone formation.

known. This study has demonstrated that renal pelvic mucosa transplanted to experimentally formed bone defects leads to a marked increase in osteogenetic activity and enhances the bridging of the bone defect by normal osseous tissue. This osteogenetic stimulus is not as well demonstrated when gallbladder mucosa or urinary bladder mucous membrane is used. It has been shown as well that such increased osteogenesis did not occur in controlled bone defects in which renal pelvic mucosa was not used. There are a few reported cases of bone formation in the human following some injury or abnormality of the urogenital tract. Occasionally, bone formation will occur after prostatectomy. A very fruitful avenue for further experimental research presents itself in the use of tissue cultures and chemical studies of the bone so produced, or of the osteoblasts responsible for this increased osteogenesis.

CONCLUSIONS

When renal pelvic mucosa of the dog is transplanted to experimental bone defects, it will materially increase the rate of osteogenesis and the speed with which bone will bridge an experimental bone defect. Other soft tissue in dogs (gallbladder, urinary bladder) does not demonstrate this marked osteogenetic characteristic. A substance or chemical which leads to osteogenesis apparently exists in uroepithelium. The nature of this substance is unknown at present.

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Penetrating Wounds of the Aorta

ARTHUR C. BEALL, JR., M.D., *Houston, Texas*

From the Cora and Webb Mading Department of Surgery, Baylor University College of Medicine, and the Jefferson Davis Hospital, Houston, Texas. This study was supported in part by U. S. Public Health Service under Grant H-3137.

THE impetus of World War II and more recently the Korean conflict, associated with the rapidly advancing technic of cardiovascular surgery, have established arterial suture as an effective procedure and the method of choice in the treatment of penetrating arterial injuries. Penetrating injuries of the aorta, however, have been largely neglected and universally considered fatal. Such an attitude is not supported by the evidence available.

As early as 1922 a laceration of the intrapericardial aorta was successfully repaired [4]. Since that time at least fourteen cases of penetrating wounds of the aorta have been reported with long term survival of the patient. (Table I.) Eight of these injuries were stab wounds and six were gunshot wounds. All were lacerations or simple puncture wounds, except one in which an aorta to right ventricular fistula was produced. The intrapericardial aorta was involved in six cases and the extrapericardial aorta in eight. The ascending thoracic aorta was injured once, the descending thoracic aorta three times, and the abdominal aorta four times. One patient did not require repair. A vitallium tube was used in one. Suture repair reinforced with a patch was used in another patient, and simple suture used in the others.

TABLE I

PENETRATING WOUNDS OF THE AORTA SUCCESSFULLY REPAIRED

Authors	Date	Cause of Injury	Location of Aortic Injury	Type of Injury	Type of Repair
Dshanelidze [4]	1922	Stab wound	Intrapericardial thoracic	1 cm. Laceration	Suture
Wildegans [16]	1926	Stab wound	Abdominal	1 cm. Laceration	Suture
Blalock [3]	1934	Stab wound	Intrapericardial thoracic	Icepick puncture	Suture
Elkin [6]	1941	Stab wound	Intrapericardial thoracic	Icepick wound	Suture
Elkin [7]	1944	Stab wound	Intrapericardial thoracic	Knife wound	Suture
Dubinskiy [5]	1944	Shrapnel wound	Abdominal	3 mm. Laceration	Suture
Holzer [8]	1948	Gunshot wound	Abdominal	5 mm. Laceration	Vitallium tube graft
Holzer [8]	1948	Gunshot wound	Abdominal	1 cm. Laceration	Suture
Beattie and Greer [2]	1952	Stab wound	Intrapericardial thoracic	14 mm. Laceration	Suture
Keeley [9]	1958	Gunshot wound	Descending thoracic	Unknown	None
Kleinert [11]	1958	Gunshot wound	Descending thoracic	1.5 cm. Laceration	Suture and patch
Perkins and Elchos [15]	1958	Stab wound	Ascending thoracic	2 cm. Laceration	Suture
Baret, DeLong, Tukanowicz and Blakemore [1]	1958	Stab wound	Descending thoracic	1.5 cm. Laceration	Suture
King and Shumacker [10]	1958	Gunshot wound	Ascending thoracic to right ventricle	1 cm. Diameter fistula	Suture

TABLE II

PENETRATING WOUNDS OF THE AORTA TREATED AT JEFFERSON DAVIS HOSPITAL SINCE 1953

Case	Age, (yr.), Sex and Race	Cause of Injury	Location of Aortic Injury	Type of Injury	Associated Injuries	Type and Repair	Results
1	24, M, W	Stab wound	Abdominal	Laceration	Small bowel	Suture	Died from renal insufficiency
2	22, M, N	Stab wound	Abdominal	Laceration	Small bowel	Suture	Survived
3	22, M, N	Gunshot wound	Descending thoracic	Laceration	Heart, liver, stomach and inferior vena cava	Suture	Died
4	30, M, N	Stab wound	Abdominal	Laceration	Mesentery and inferior vena cava	Suture	Died
5	31, M, N	Gunshot wound	Abdominal	Laceration	Liver	None	Died
6	23, M, N	Gunshot wound	Abdominal	Laceration	None	Suture	Survived
7	50, M, N	Gunshot wound	Descending thoracic	Laceration	Heart	None	Died
8	24, M, W	Stab wound	Intrapericardial thoracic	Aorta to right ventricular fistula	Small bowel* and mesentery	Suture†	Survived
9	42, M, N	Gunshot wound	Abdominal	Laceration	Large bowel	Suture	Died
10	37, M, N	Gunshot wound	Descending thoracic	Laceration	None	None	Died
11	31, M, N	Gunshot wound	Abdominal	Laceration	Small bowel, large bowel and inferior vena cava	Prosthesis	Died in recovery room
12	42, M, N	Gunshot wound	Abdominal	Laceration	Small bowel and large bowel	Suture	Died
13	24, M, N	Gunshot wound	Abdominal	Laceration	Small bowel and duodenum	Suture	Survived
14	24, M, W	Stab wound	Abdominal	Laceration	Small bowel and inferior vena cava	Suture	Died from renal insufficiency
15	33, M, N	Stab wound	Descending thoracic	Laceration	None	None	Died
16	28, M, N	Stab wound	Descending thoracic	Laceration	Pulmonary artery	None	Died
17	22, M, W	Gunshot wound	Abdominal	Laceration	Liver, kidney, duodenum and large bowel	Suture	Survived
18	23, M, N	Gunshot wound	Abdominal	Laceration	Small bowel and liver	None	Died
19	31, M, N	Gunshot wound	Transverse arch	Laceration	None	None	Died
20	50, M, N	Stab wound	Intrapericardial thoracic	Aorta to right ventricular fistula	None	Suture†	Survived
21	47, F, N	Gunshot wound	Abdominal	Destruction	Liver, spleen, small bowel and mesentery	None	Died
22	29, M, W	Gunshot wound	Abdominal	Laceration	Liver and pancreas	None	Died
23	17, M, N	Gunshot wound	Descending thoracic	Laceration	Liver	Suture	Survived

* Reapired on original admission.
† Delayed repair utilizing cardiopulmonary bypass.

These reports have dealt primarily with single successful cases and do not afford a concise picture of penetrating aortic injuries. For this reason an analysis has been made of all patients with penetrating wounds of the aorta seen since 1953 at the Jefferson Davis Hospital, a city-county general hospital for the indigent. (Table II.) Several of these patients were briefly mentioned in a previous report on arterial injuries [*12*]. All patients showing any sign of life on arrival are included. Resuscitation and repair were performed for the most part by the resident staff.

INCIDENCE AND TYPE OF INJURY

Twenty-two patients were males and one was a female. The majority were in the second and third decade of life, although their ages varied from seventeen to fifty years. Eighteen were Negro and five were white. Stab wounds produced eight injuries and gunshot wounds caused the other fifteen. Two injuries resulted in an aorta to right ventricular fistula. (Fig. 1.) These have been reported in detail elsewhere [*13*]. The remaining injuries were tangential or through-and-through lacerations, except one fatal case in which a large portion of the abdominal aorta was destroyed by a shotgun blast at short range.

LOCATION OF INJURY

Penetrating wounds of all areas of the aorta are included. (Fig. 2.) The intrapericardial aorta was involved in the two cases of an aorta to right ventricular fistula. In twenty-one cases involving the extrapericardial aorta seven were

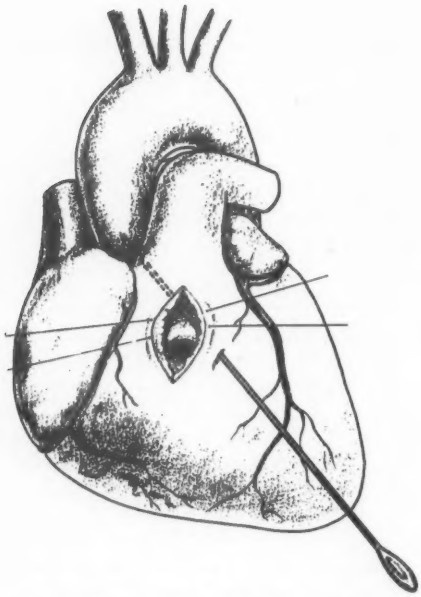

FIG. 1. Case VIII. Aorta to right ventricular fistula.

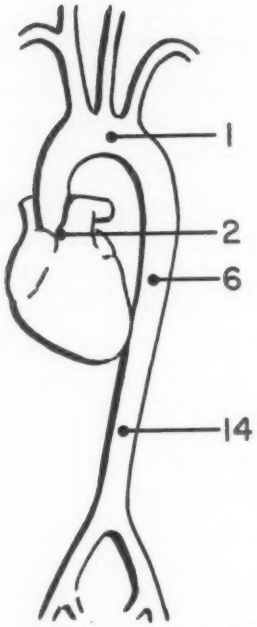

FIG. 2. Location of aortic injuries.

of the thoracic aorta and fourteen of the abdominal aorta. Of those involving the thoracic aorta the transverse arch was injured once and the descending aorta six times.

ASSOCIATED INJURIES

In nineteen patients thirty-six major associated injuries were present. (Table III.) The intraperitoneal small bowel and liver were the most frequently involved structures, being injured nine and seven times respectively. Injuries to the large bowel and the inferior vena cava were seen four times each. Significant involvement of the mesentery of the small or large bowel was present in three patients. Excluding the two cases of aorta to right ventricular fistula, a laceration of the heart was present in two other patients. The duodenum was also injured in two patients. Injuries to the stomach, spleen, pancreas, kidney and pulmonary artery were each noted once.

TABLE III
ASSOCIATED INJURIES IN NINETEEN PATIENTS WITH PENETRATING WOUNDS OF THE AORTA

Location of Injury	No.
Extraperitoneal small bowel	9
Liver	7
Large bowel	4
Inferior vena cava	4
Mesentery	3
Heart	2
Duodenum	2
Stomach	1
Spleen	1
Pancreas	1
Kidney	1
Pulmonary artery	1
Total	36

CONDITION OF PATIENTS

When first seen all patients except one were in shock. In two patients blood pressure rose to normotensive levels following the administration of intravenous colloid solution only. Two others with low blood pressure failed to respond until blood infusions were started. The remaining eighteen patients had no detectable blood pressure on arrival. Of these, five had either a palpable pulse or heart sounds. In twelve the only sign of life was the presence of respiratory effort. The other patient probably was dead on arrival, but is included because a gasp was noted just prior to arrival; cardiac massage was performed, and spontaneous cardiac action was

re-established for twenty minutes before arrest again occurred.

RESUSCITATION

Resuscitation was instituted immediately by the intravenous insertion of large bore polyethylene catheters. Colloid solution was given until uncrossmatched, type O negative, whole blood could be started. Vasopressors were used as indicated. Specific type, crossmatched, whole blood was given as soon as available, and was the only type of blood given in several cases. Blood replacement varied from none in patients surviving only a few minutes to a high of 15,000 ml., and averaging 6,250 ml.

The time interval from arrival at the hospital to the beginning of operation in sixteen patients varied from five to 125 minutes, averaging thirty-two minutes. Seven patients did not survive long enough to be moved to the operating room. Two others survived less than one hour after arrival.

REPAIR

Simple suture was the predominant method of aortic repair. The method was used in all successful cases, including both cases of aorta to right ventricular fistula repaired utilizing cardiopulmonary bypass. An aortic bifurcation prosthesis was used in one fatal case. No effort was made to repair the aorta in nine patients.

RESULTS

Ten of twenty-three patients survived the operation, although one died in the recovery room shortly thereafter. There were two late deaths from renal insufficiency, leaving seven long term survivors. The major cause of death was irreversible shock, with the extent of total injury contributing heavily. Long term survivors include two patients with aorta to right ventricular fistulas from stab wounds, one with a descending thoracic aortic injury from a gunshot wound, and four with injuries of the abdominal aorta, one from a stab wound and three from gunshot wounds. One long term survivor was temporarily readmitted to the hospital with homologous serum hepatitis. All were asymptomatic when last seen.

COMMENTS

A review of 384 postmortem cases of penetrating wounds of the heart and aorta has shown that 15.7 per cent of patients survived the immediate effect and 12.2 per cent survived over one hour, long enough to receive medical attention [*14*]. In order to salvage a portion of these patients reaching hospital facilities, resuscitation must be prompt and effective. It is not possible on admission to determine which patients will survive and which will not. All must be considered to be salvageable.

Massive blood replacement is required, and facilities for this must be at hand. Not only must large quantities of blood be available, but a route of administration must be assured. The intravenous insertion of large bore polyehtylene catheters has been found to be satisfactory for this purpose. In cases in which the wound is below the diaphragm, an upper extremity vein should be used, due to the frequency of associated injury to the vena cava.

Early operation does not follow resuscitation but is an integral part of it. Further blood loss must be stopped as early as possible. In general, the plan of operation is first to control aortic bleeding by pressure, following which the aorta above and below the injury is isolated and clamped. Attempts at primary isolation of the aorta above and below the injury are usually met with further massive blood loss and failure. Occasionally, temporary clamping of the thoracic aorta is helpful in the management of injuries to the abdominal aorta, but primary control is with pressure. Once aortic hemorrhage is controlled, other bleeding is stopped. Repair is then performed in the order dictated by the particular case.

SUMMARY

Penetrating wounds of the aorta are not necessarily fatal. At least fourteen successful cases have been reported previously. The present series consists of twenty-three patients with penetrating aortic injuries, treated in a city-county general hospital. With the rapid institution of resuscitative measures in all patients with any sign of life on arrival, ten (43.5 per cent) survived operation and seven (30.5 per cent) were long term survivors. With a salvage rate of this magnitude in an injury generally considered fatal, attempted resuscitation and repair is mandatory.

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Surgical Experience with 220 Acute Arterial Injuries in Civilian Practice

GEORGE C. MORRIS, JR., ARTHUR C. BEALL, JR., W. R. ROOF AND MICHAEL E. DE BAKEY, *Houston, Texas*

From the Cora and Webb Mading Department of Surgery, Baylor University College of Medicine, Houston, Texas. This study was supported in part by U. S. Public Health Service under Grant No. H-3137.

RECONSTRUCTIVE arterial surgery began nearly 200 years ago with the successful repair of a laceration of the brachial artery [1]. Despite pioneering efforts of many surgeons in following years, only in the past decade has primary repair of acute arterial injuries replaced ligation as accepted operative treatment. For example, in an analyzed series of 2,471 acute arterial wounds from World War II, end-to-end anastomosis was accomplished in only three instances [2]. Isolated efforts during this conflict, however, did demonstrate the brilliant achievements possible with primary repair.

Recent years have brought notable advances in almost every area of vascular surgery which are reflected in reports of arterial injuries in latter-day conflicts [3–6]. Restoration of normal blood flow, not merely saving life, is now accepted in the treatment of patients with acute arterial injury involving the extremities as well as trauma to major vessels in the chest and abdomen. Thus the surgeon's opportunities as well as duties have been projected far beyond the previously accepted treatment of ligation or amputation. Arterial repair is indicated in every major arterial injury, and only the most serious extenuating circumstances should allow deviation from this objective. Only by repair can normal circulation be restored in peripheral tissues. Furthermore repair avoids later complications such as pulsating hematoma, false aneurysm and arteriovenous fistula.

We have had the opportunity to manage 220 acute arterial injuries in civilian practice during a period of ten years. Peacetime surgery should provide the most favorable circumstances for primary repair of arterial injuries because the interval between injury and repair tends to be shorter, and massive soft tissue injury as from high velocity missiles is less frequent. (Table 1.) Restoration of distal pulses occurred in 86 per cent of the cases treated by primary repair. The gratifying results seen in this civilian series illustrate the distinct advantage the peacetime surgeon has compared with the military surgeon. (Fig. 1.)

SURGICAL METHODS

Four basic technics have been utilized in the repair and restoration of blood flow for acute arterial trauma. These consist of lateral repair, end-to-end anastomosis, replacement graft and bypass graft. Two fundamental factors generally govern the selection of the technic to be employed in each case: namely, the type and location of the injury. Success in the treatment of vascular injuries is quite dependent on atten-

TABLE 1
ASSOCIATED INJURIES IN 220 CASES OF ACUTE ARTERIAL INJURIES

Injury	No.
Injury to adjacent nerves	48
Injury to major veins	30
Abdominal injury	30
Injury to adjacent tendons	26
Fracture of adjacent bone	22
Extensive soft tissue injury	20
Thoracic injury	16
Other	12
Fracture of other bones	9
Dislocation of adjacent joint	3
Total	225

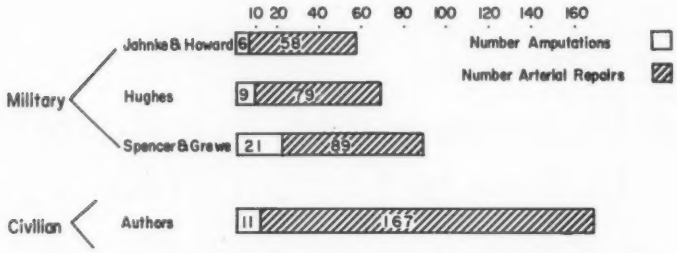

FIG. 1. Comparison of incidence of amputation following arterial repair in three military reports from Korean war and our civilian series. Better results follow arterial repair in civilian injuries primarily because of infrequency of massive soft tissue trauma.

tion to small details and fastidious technic. Exposure and dissection of the injured artery must be adequate proximally and distally. Hemorrhage during initial dissection usually can be controlled by digital pressure followed by subsequent placement of appropriate non-crushing vascular clamps or tapes above and below the point of injury.

Lateral Repair. Direct suture repair may be employed in clean linear lacerations involving only a segment of the arterial wall, such as those produced by glass, knives and other sharp objects. Occasionally, expeditious lateral repair may be indicated in gunshot wounds of the carotid arteries and aorta produced by small caliber, low velocity firearms to facilitate a shorter period of occlusion and prevent irreversible cerebral or spinal cord damage. If necessary the edges of the arterial wound may be débrided before suture repair. Any fine atraumatic non-absorbent suture material may be used such as silk or dacron. A continuous over-and-over everting suture effects a most satisfactory repair. (Fig 2.) Too much emphasis cannot be placed on the importance of flushing the artery both proximally and distally through a small opening in the repair before removing the occluding clamps. Gentle retrograde massage may be of further aid in the removal of possible clots formed in the vessel during the period of occlusion. In this connection it is generally wise to inject 10 to 20 mg. of heparin into the distal portion of the artery immediately after occlusion. However, local anticoagulants will not insure the prevention of clots adjacent to the points of occlusion. Only adequate proximal and retrograde flushing will insure an open artery. After release of the clamps, palpable distal pulses should be present. When absent, arteriography on the operating table may be necessary to rule out mechanical impediment to pulsatile blood flow.

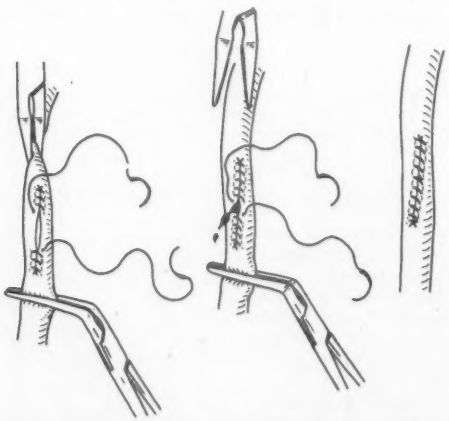

FIG. 2. Technic of lateral repair for simple lacerations of the arterial wall. Flushing proximally and distally before final release of occluding clamps is essential.

End-to-End Anastomosis. Direct end-to-end anastomosis should be utilized in all severed arteries when approximation can be effected without tension. Commonly the edges should be trimmed back to the healthy arterial wall. In smaller arteries oblique tailoring of the ends allows a larger lumen at the point of union. In jagged irregular wounds and most gunshot injuries resection of a small segment of the injured vessel is usually necessary. Two factors of great importance should be observed in avoiding tension: namely, mobilization of the artery proximally and distally to obtain the advantage of normal arterial elasticity, and flexion of the adjacent joint to foreshorten the

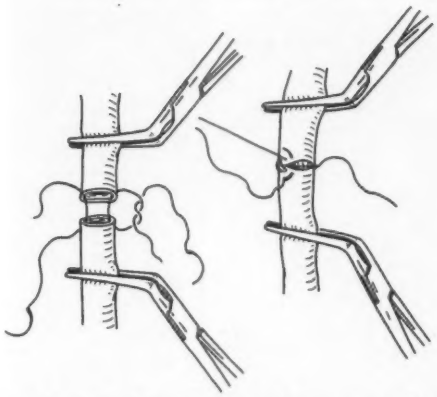

FIG. 3. Technic of direct end-to-end anastomosis. Application of two principles helps to avoid tension, namely arterial mobilization and flexion of adjacent joint.

artery. Anastomosis is usually made easier by placing two or three anchoring sutures as first described in the triangulation technic of Carrel. (Fig. 3.) A continuous over-and-over suture of fine atraumatic non-absorbent material is most commonly employed. Again the importance of flushing the artery through a small aperture before completing the anastomosis is of extreme importance. When resection and end-to-end anastomosis must be performed for injury to the carotid artery, utilization of an internal shunt will provide for cerebral circulation during repair and prevent cerebral ischemic damage. (Fig. 4.)

Replacement Graft. In some instances end-to-end anastomosis without tension cannot be accomplished despite adequate mobilization and flexion of the adjacent joint; suitable grafts are now readily available and should be em-

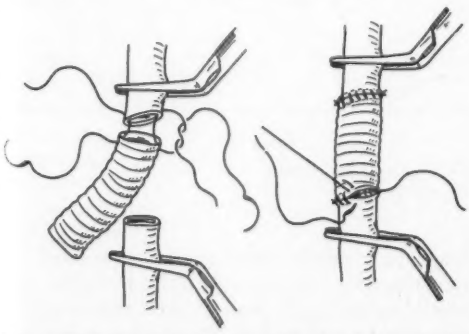

FIG. 5. Technic utilized in restoring arterial continuity with a graft when loss of substance prevents direct end-to-end anastomosis.

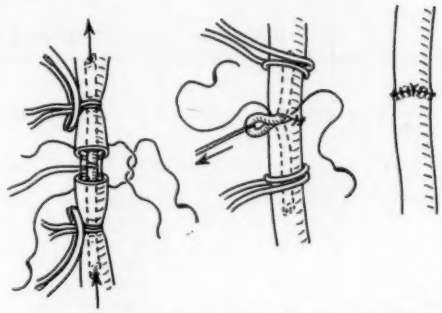

FIG. 4. Application of internal shunt to avoid cerebral ischemia during repair of carotid artery.

ployed to re-establish arterial continuity. Knitted Dacron® grafts have been quite successful in our series. The diameter of the graft should be slightly larger than the injured artery. End-to-end anastomosis of the artery to the graft is similar to direct anastomosis. (Fig. 5.) Proximal anastomosis should be completed first and flushing should be performed before completing the distal union. Preclotting of the interstices of fabric grafts and slow release of the proximal occluding clamp will minimize blood loss.

Bypass Graft. Certain unusual arterial injuries, particularly those caused by blunt trauma, may be associated with subintimal or medial dissection of blood over relatively long distances. In such instances a bypass graft may be employed to reconstitute blood flow to the extremity. (Fig. 6.) If the outer wall including the adventitia has not been disrupted a side-to-end proximal anastomosis may be used to attach the graft to the open artery above the point of dissection. The distal anastomosis of the bypass graft may be end-to-end or end-to-side with the patent distal artery.

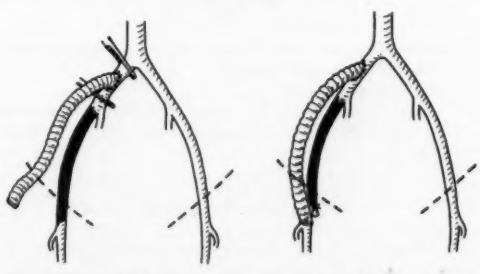

FIG. 6. Application of bypass principle for restoring arterial continuity when subintimal dissection has produced a long area of occlusion.

TABLE II

RESULTS OF TREATMENT IN 220 CASES OF ACUTE ARTERIAL INJURY

Artery	Treatment	No. of Cases	Immediate Pulse	Delayed Pulse	No. of Pulses Viable	Amputation	Death
Carotid	Repair:						
	Suture	12	11*	..	..	..	1
	Graft	1	1	..	..	..	..
	Ligation	3	...	..	3†	..	..
	None	2	...	..	..	..	2
Aorta	Repair:						
	Suture	13	9‡	..	..	..	4
	Graft	1	...	..	..	..	1
	None	9	...	..	..	..	9
Subclavian and axillary	Repair:						
	Suture	12	12	..	..	..	..
	Graft	3	3	..	..	..	..
	Ligation	3	...	..	1	1	1
	None	1	...	..	..	..	1
Brachial	Repair:						
	Suture	44	35	5	2	2	..
	Graft	5	3	1	..	1	..
	Ligation	5	...	1	1	2	1
	Exploration	1	...	1	..	..	..
Iliac	Repair:						
	Suture	13	8	..	..	2	3
	Graft	2	1	..	..	..	1
	Ligation	1	...	..	..	1	..
	None	1	...	..	..	..	1
Femoral	Repair:						
	Suture	25	19	5	..	1	..
	Graft	8	4	1	1	2	..
	Ligation	2	...	..	2	..	..
	Exploration	1	1	..	..	..	..
Popliteal	Repair:						
	Suture	9	7	..	..	2§	..
	Graft	2	2	..	..	..	..
	Exploration	3	2	..	1	..	..
Radial and ulnar	Repair:						
	Suture	14	13	..	1	..	..
	Graft	1	1	..	..	..	..
	Ligation	18	...	..	18	..	..
Anterior and posterior tibial	Repair:						
	Suture	2	1	1	..	..	..
	Ligation	3	...	..	2	1	..
Total		220	133	15	32	15	25

* Hemiplegia, one patient.
† Hemiplegia, two patients.
‡ Two patients survived over twenty-four hours, but died of acute renal failure.
§ One viable extremity amputated because of massive soft tissue loss.

ANALYSIS OF CASES

Primary arterial repair was accomplished in 167 patients. (Table II.) Lateral suture or end-to-end anastomosis was performed in 144 patients and twenty-three required a graft. Gunshot wounds were generally treated by resection and end-to-end anastomosis, and small shotgun pellet wounds were sutured without resection. Small caliber bullet wounds of the carotid arteries and aorta were simply closed by suturing when this was technically

FIG. 7. Photograph taken at operation showing completed repair of a laceration of the carotid artery. Internal shunt was not utilized because injury interrupted arterial flow without producing neurologic alteration.

feasible. In injuries of the carotid artery it was sometimes possible to avoid prolonged cerebral ischemia and resultant hemiplegia by this approach.

Primary repair of the common or internal carotid artery was performed in thirteen cases. In nine of these cases simple lateral repair was attended with no neurologic sequelae. (Fig. 7.) In other cases resection and anastomosis were necessitated by severe damage and loss of substance of the artery, and in one instance it was necessary to use a graft to restore arterial continuity. In one case in which end-to-end anastomosis was performed without an internal shunt, prolonged occlusion resulted in hemiplegia.

Repair was completed in fourteen of twenty-three wounds of the aorta with early survival in nine cases. Gunshot perforations of the aorta were closed by lateral suture without constriction of the lumen. In one knife wound with almost complete severance of the aorta, repair

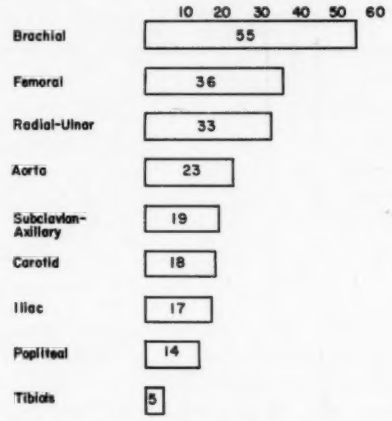

FIG. 8. Relative frequency of injury to major arteries. Brachial and femoral arteries are most frequently injured because of their length and vulnerability.

was successful but a transfusion reaction led to the patient's death on the twenty-third postoperative day as a result of renal insufficiency. Resection and graft replacement were necessary in treating one shotgun wound of the abdominal aorta; however, the patient died.

Fifteen subclavian and axillary arterial wounds were repaired, three of which required a graft, and in all instances there was immediate restoration of pulses. The brachial artery was injured most frequently in this series. (Fig. 8.) Forty-nine injuries of the brachial artery were repaired: in forty-four cases, radial pulses developed; amputation was necessary in three unsuccessful cases; and the other two patients had viable arms without pulses. One of these amputations was necessary in the five instances in which a graft was employed.

Fifteen injuries of the iliac artery were repaired and pulse was restored in nine instances. In the six failures two patients had amputation and four died. A graft was employed twice in this group and represented one successful case and one death. A graft was used in eight of thirty-three repairs of the femoral artery. A graft was used in eight of twenty-nine instances in which pulse was restored and represented two of four failures. One such patient had a viable leg without pulses and three patients had amputation. The popliteal artery was repaired in eleven patients. Pulse was restored in nine of these and amputation was necessary in the two repair failures. It is interesting that one amputation was necessitated despite pedal

TABLE III
TYPE OF WOUND

Wound	No. of Cases
Transection	107
Laceration	98
Contusion	11
Spasm	4
Total	220

pulses in a viable distal extremity because of massive soft tissue loss and infection associated with a shotgun wound. Fifteen radial and ulnar arteries and two posterior tibial arteries were repaired and pulse developed in all but one case.

Suture of longitudinal and transverse lacerations was employed except when resection and anastomosis were necessary to avoid luminal constriction or to excise traumatized arterial wall. End-to-end anastomosis was performed when feasible in the 107 arterial transections. (Table III.) If loss of substance or subintimal dissection made direct anastomosis impossible the defect was bridged with a graft. It was necessary to resort to replacement with a graft in twenty-three cases. Homografts were utilized in fourteen cases and knitted Dacron grafts in nine recent cases. The graft was used as a long bypass in one case in which an intimal

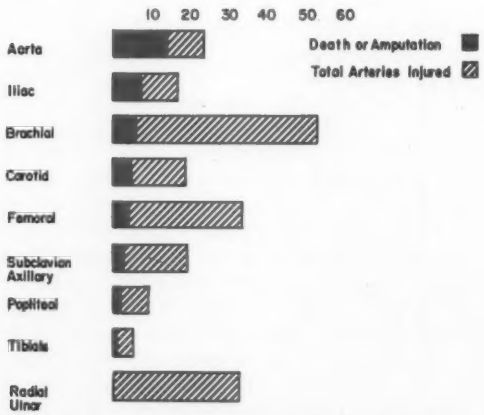

FIG. 9. Incidence of death or amputation according to artery injured. Injuries of the aorta and iliac artery have highest mortality because of massive hemorrhage and difficulty in obtaining immediate control. Shaded segment represents death or hemiplegia from carotid injuries.

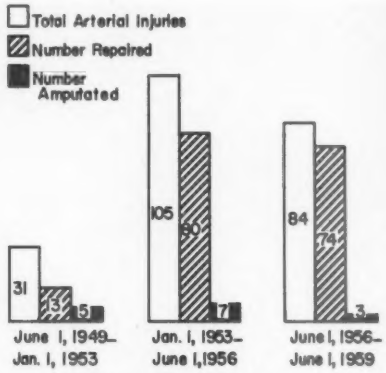

FIG. 10. Comparison as to frequency of repair and incidence of amputation in three periods of ten-year study. Improved technic and high incidence of repair are responsible for reducing amputations.

tear caused by blunt trauma was followed by subintimal dissection from the common iliac to superficial femoral artery. In all other instances the grafts were sutured end to end with simple over-and-over everting sutures of fine silk or dacron. Heparin usually was employed locally but postoperative anticoagulant therapy was not utilized.

Pulse returned with viable extremities in 86 per cent of cases in which repair was completed. In twenty-four patients with unsuccessful repair four had viable extremities without pulses, ten underwent subsequent amputation and ten died.

Ligation was resorted to in thirty-five instances and most of these patients were operated upon in the early years of the series. In twenty-one instances of ligation the wounds were of the radial, ulnar or tibial arteries. One ligation of the posterior tibial artery was followed by amputation. Viable extremities followed ligation in twenty-six cases. Of the remaining cases with wounds of larger arteries treated by ligation five resulted in amputation and two in death. Two of three carotid injuries managed by ligation were followed by hemiplegia.

Exploration without arteriotomy relieved simple compression from associated fracture in two patients and severe arterial spasm in three others. In thirteen patients death from hemorrhage occurred before repair could be performed. Most patients in this group had injuries to the aorta, or subclavian or iliac arteries. (Fig. 9.)

Division of the study into three periods relative to treatment and results has demonstrated increasing utilization of immediate repair and decreasing incidence of amputation. (Fig. 10.) During the last two periods of the study, repair was effected in 89 per cent of all arterial injuries seen. Moreover the incidence of amputation following an arterial wound fell from 16 per cent in the first period to 6.6 per cent in the second, and finally to 3.6 per cent during the last period of the study.

SUMMARY

During the past decade 220 cases of acute arterial injuries were encountered in civilian practice. Primary repair was performed in 167 instances with restoration of peripheral pulse in 86 per cent of these cases. A graft was employed in the repair of twenty-three cases. Amputation was necessary following unsuccessful repair in eleven patients.

The four basic technics employed in arterial reconstruction were lateral suture, end-to-end anastomosis, graft replacement and bypass graft. Immediate repair of all arterial wounds should be performed except under the most extenuating circumstances. Attention to minute details and fastidious technic provide the greatest opportunity for salvage of life and limb.

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Pericardial Tamponade

NEWER DYNAMIC CONCEPTS

J. WALTER MARTIN, M.D. AND WORTHINGTON G. SCHENK, JR., M.D., *Buffalo, New York*

From the Department of Surgery, University of Buffalo School of Medicine and the Edward J. Meyer Memorial Hospital, Buffalo, New York. This study was supported in part by Grant H-3181 from the U. S. Public Health Service and a grant from the Erie County Heart Association.

INTEREST in the physiological aspects of pericardial tamponade was first stimulated by Cohnheim [1] in 1889. Using oil as the tamponade agent, he showed that with a rise in intrapericardial pressure there was a fall in peripheral blood pressure. Later, the problem was again studied by Starling [6]. More recently Metcalfe et al. [4] and Isaacs and co-workers [3] have contributed to the knowledge of tamponade.

Two-thirds of the patients with penetrating cardiac wounds who reach a hospital alive exhibit pericardial tamponade as the single life endangering complication. Fuller understanding of this complication is thus of paramount importance to successful management of patients with such injuries.

The newer electronic technics for determination of pressure and flow have made possible experimental studies in tamponade which hitherto were impossible. Although the qualitative effects in cardiac tamponade have been known for some time it has not been possible to quantitate the changes accurately.

This study involves the recording of alterations in pericardial pressure, arterial pressure, venous pressure and left ventricular output as the volume of fluid in the pericardial sac is acutely and progressively increased.

METHOD

Nine healthy adult mongrel dogs with an average weight of 21.8 kg. were used in this

FIG. 1. General view of apparatus employed in investigation of experimental pericardial tamponade.

tudy. Anesthesia was induced with the ntravenous administration of sodium pentothal nd maintained at a stable level with intra- enously administered Nembutal.® Respiratory xchange was supplied by a positive-negative entilator. The apparatus utilized in the xperiments is shown in Figure 1.

The left side of the chest of the animal was pened and a large bore polyethylene catheter, 35 cm. in length, was introduced into the pericardial sac through a small incision; it was hen tied in securely with a silk ligature making he catheter-pericardial junction watertight. The polyethylene tube was marked at 1 cm. intervals and then suspended in the vertical plane.

Catheters were introduced into the femoral vein and artery for recording of arterial and venous pressures. The arterial blood pressure was recorded by a capacitance bridge manometer and the venous pressure recorded by a simple "U" water manometer.

Graduated quantities of saline were introduced into the pericardial sac by way of the large polyethylene catheter. The saline was colored with sky blue dye so that any leakage from the pericardial sac could be detected. This is demonstrated in Figure 2.

Through the open chest, cardiac output less coronary blood flow was measured using the

FIG. 2. The pericardial catheter and dye-colored fluid in the pericardial sac are well demonstrated here. At the right, a flow probe is shown.

square-wave electromagnetic flowmeter* as described by Denison and Spencer [2]. A flow probe is also seen in Figure 2. The cardiac output was determined after each increment in pericardial fluid. This was measured by the summation of the flows through the descending thoracic aorta, the brachiocephalic and left

* Made by Kiger-Dennard Associates, Winston-Salem, North Carolina.

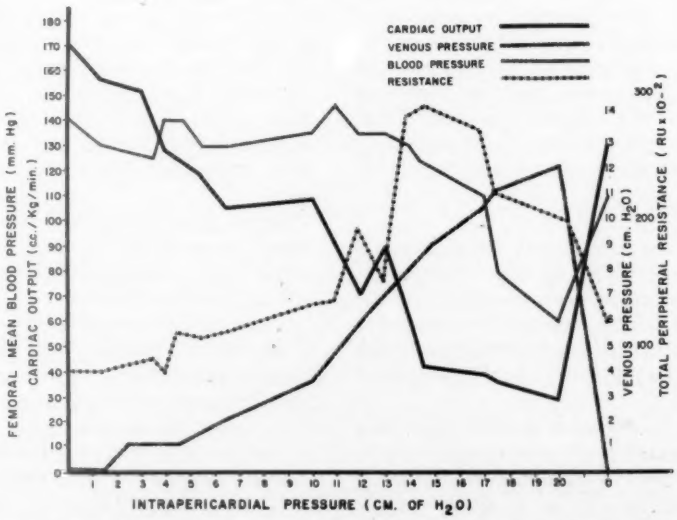

FIG. 3. Experimental cardiac tamponade. Alterations in mean arterial pressure, cardiac output, venous pressure, and calculated peripheral resistance with progressive elevation of intrapericardial pressure. Experiment No. 520.

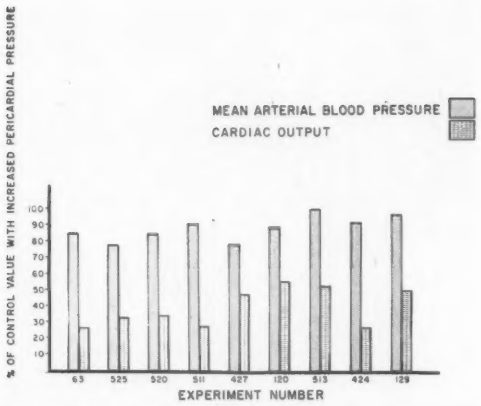

FIG. 4. Per cent decrease of arterial blood pressure and cardiac output in experimental cardiac tamponade while blood pressure still is within normal range.

subclavian arteries. The amount of saline injected into the pericardial sac varied between 10 and 25 cc. per increment depending upon the size of the dog and reached total volumes of 100 to 200 cc.

In addition, after each increase in pericardial fluid, the intrapericardial pressure and the peripheral blood pressure were measured. In three dogs venous pressure was measured after each increment in pericardial volume.

Increments in pericardial volume were continued until it was thought that circulatory arrest was imminent. The fluid was then removed rapidly and cardiac output, arterial blood pressure and venous pressure measured immediately in the recovery period. Total peripheral resistance was calculated by dividing mean arterial blood pressure by cardiac output.

RESULTS

Figure 3 shows the results from a single typical experiment. Along the abscissa is plotted intrapericardial pressure and along the ordinate on the left are plotted femoral mean blood pressure and cardiac output. On the right are plotted venous pressure and total peripheral resistance.

In this typical experiment it can be seen that as intrapericardial pressure rose, cardiac output gradually fell from 170 cc./minute/kg. of body weight to 30 cc./minute/kg. of body weight. At the same time, the venous pressure rose from 0 to 12 cm. of water. Total peripheral resistance likewise showed an increase from 4 to 14.5 resistance units. Of particular interest is the fact that the blood pressure remained relatively stable even after cardiac output had fallen significantly and venous pressure had risen considerably. When the femoral mean arterial pressure was 110 mm. Hg, the cardiac output was 42 per cent of the control value. At the same time, venous pressure had increased from 0 to 10 cm. of water.

In the recovery period the mean arterial blood pressure returned to 130 mm. Hg, cardiac output to 110 cc./minute/kg. of body weight, the venous pressure to 0 and the total peripheral resistance to 6 resistance units. All these values are within normal limits.

In Figure 4 is shown the percentage of the control value of cardiac output and femoral mean blood pressure recorded after intrapericardial pressure had been increased significantly, but while the blood pressure was still within the normal range. In all nine animals, the blood pressure was maintained or slightly depressed while cardiac output was markedly depressed from the control value. There was a 12 per cent average decrease in mean arterial pressure while, at the same time, there was a 63 per cent average decrease in cardiac output from the control value in all nine animals.

Figure 5 is a scattergram of the cardiac output values from all experiments over the entire range of increments in pericardial pressure. The cardiac output falls in a linear fashion as intrapericardial pressure increases. During the recovery period, the cardiac output returned to an average of 100 cc./minute/kg. of body weight. This is within the normal range of cardiac output for the dog which is based on work carried out previously in this laboratory [5].

Figure 6 is a scattergram of mean arterial blood pressure in all experiments over the entire range of pericardial pressures. The mean arterial blood pressure remained stable until an intrapericardial pressure between 13 and 16 cm. of water was reached and then fell, often precipitously. During the recovery period, the blood pressure returned to an average of 112 mm. Hg for all animals.

Figure 7 is another scattergram of the venous pressure obtained in three dogs with increasing intrapericardial pressures. As can be seen, the venous pressure increased in a linear manner with a rise in intrapericardial pressure. In all three experiments, after the pericardial fluid

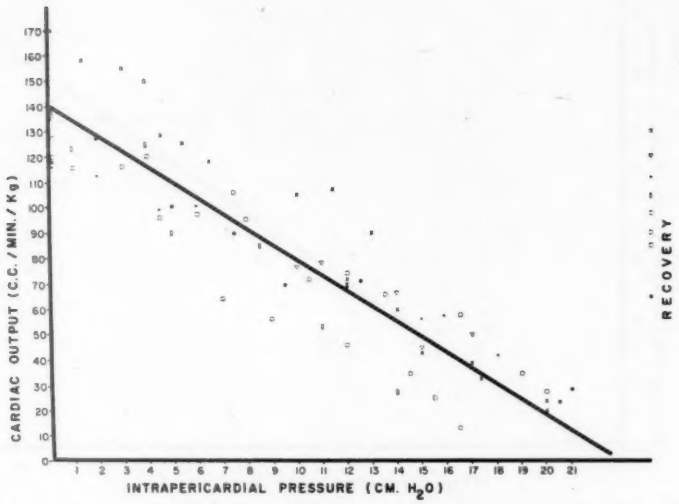

FIG. 5. Alteration in cardiac output with progressive increase in pericardial pressure. Scattergram of data from nine experiments. (The heavy line is a calculated linear regression line which is statistically significant; $p < 0.001$.)

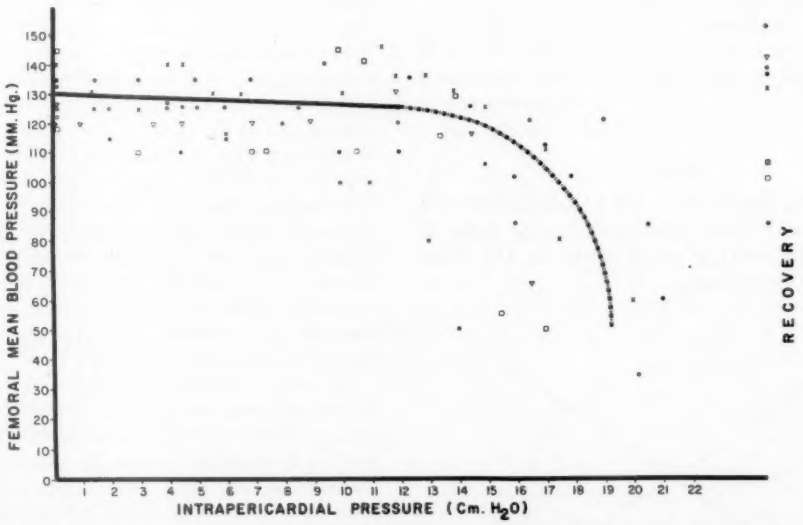

FIG. 6. Alteration in mean arterial blood pressure with progressive increase in pericardial pressure. Scattergram of data from nine experiments. (The heavy line is a linear regression line arbitrarily calculated from the points between 0 to 12 cm. water; over this range there was a high degree of correlation to this line, but the slight apparent slope to the line is not statistically significant; $0.30 > p > 0.20$. The dotted portion of the curve is merely a visual fit to the data suggesting an exponential curve but not statistically confirming to it probably because of the wide scatter of the data over this range.)

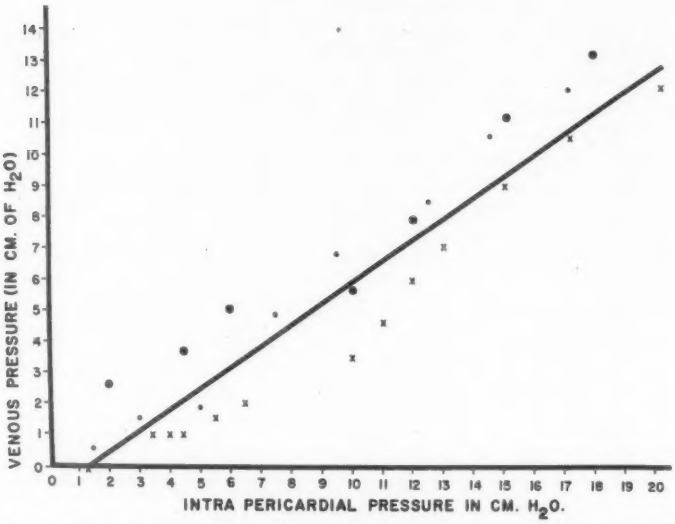

FIG. 7. Alteration in venous pressure with progressive increase in pericardial pressure. Scattergram of data from three experiments. (The heavy line is a calculated linear regression line which is statistically significant; $p < 0.001$.)

was removed during the recovery period, the venous pressure returned to 0.

Total peripheral resistance in the nine animals remained stable in the early phases of tamponade or rose slightly and did not show a marked rise until the blood pressure started to fall and cardiac output had fallen considerably.

COMMENTS

It would appear from our experimental work that arterial blood pressure is a poor index of the cardiac output particularly in the early phases of tamponade.

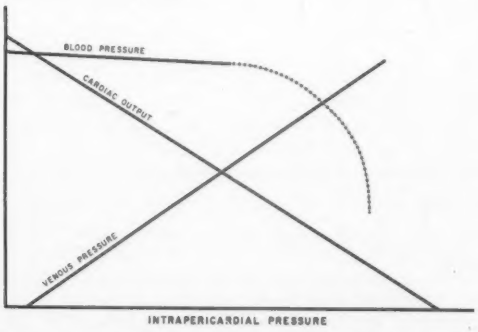

FIG. 8. Diagram summarizing alterations in arterial blood pressure, cardiac output, and venous pressure as intrapericardial pressure is acutely and progressively increased.

From the evidence herein presented it would seem that arterial blood pressure is maintained despite a marked fall in cardiac output by a progressive increase in peripheral resistance in all probability due to peripheral vasoconstriction. When the blood pressure finally fell, the animal was at the point of circulatory cessation. We believe that, in patients, the blood pressure is probably also a poor indication of the circulatory status as the blood pressure may be normal although cardiac output may be as low as one-third of the normal value. Blood pressure, of course, is of significance if it is markedly depressed since it indicates that circulatory collapse is imminent and rapid pericardial aspiration may be lifesaving.

It would appear that venous pressure is a better indicator as to the status of the circulatory system in cardiac tamponade. We believe that, in human beings, simple measurement of the venous pressures over short intervals of time may give an accurate impression of the degree of circulatory impairment resulting from tamponade when the surgeon is in doubt.

CONCLUSIONS

The principal conclusions are illustrated in Figure 8 and are as follows:

1. Cardiac output fell in a linear fashion as the intrapericardial pressure was increased.

2. Arterial blood pressure did not fall appreciably until the later phases of tamponade.

3. Venous pressure rose in a linear fashion as the intrapericardial pressure was increased.

4. Total peripheral resistance remained stable during the inital phases of tamponade and then increased.

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Gunshot Wounds of the Heart

A REVIEW OF TWENTY CASES

HERBERT T. RANSDELL, JR., M.D., *Louisville, Kentucky,* AND HENRY GLASS, JR., M.D., *Charleston, West Virginia*

From the Department of Surgery, University of Louisville and Louisville General Hospital, Louisville, Kentucky. This study was supported in part by the Mr. and Mrs. Albert Wilhelm Fund for Surgical Research.

A REVIEW of the available literature does not reveal a single sizable series of gunshot wounds of the heart encountered in civilian practice. Most reports refer to but one or two cases, or include a few among groups of heart wounds of all types. Samson [1] analyzed fifty-seven wounds of the heart resulting from shell fragments and small arms fire in World War II.

Our series of twenty consecutive patients with proved gunshot wounds involving the heart were admitted to the Louisville General Hospital from 1934 to the present. (Table 1.) This includes all patients showing any manifestation of life when admitted to the emergency room. Any patient in whom a skin incision was started is counted as an operative case even if he died before the chest was opened. Although these are very strict criteria we believe they most accurately reflect the effect of the whole program on the management of these wounds. Fifteen of these patients were operated upon with seven survivals. Four died in less than ten minutes after admission and before surgery could be started. One was treated without operation, and died. The survival rate was 35 per cent for the series with 100 per cent mortality for those without operation and 47 per cent for those with surgery.

DIAGNOSIS

In most cases the diagnosis or at least the indication for immediate thoracotomy can be definitely established on history and physical examination alone. During the earlier years of this study, time-consuming diagnostic tests, such as venous pressures, fluoroscopy and pericardiocentesis, were used rather extensively with much transporting between the wards, x-ray, emergency and operating rooms. Due to the loss of or marked and rapid deterioration of several of these patients during these various procedures we have standardized on only physical examination and an occasional portable x-ray film of the chest. The only exceptions are with patients in extremely good condition whose diagnosis is in doubt.

Education of the house staff, particularly those of the emergency and operating rooms, in the diagnosis of a heart wound, and immediate institution of treatment is of paramount importance in the management of these wounds. The staff must be constantly alert that a wound of the heart can occur in practically any penetrating wound of the chest or upper abdomen. This is particularly true when shock seems out of proportion to the apparent severity of the wound or loss of blood. Unfortunately acute alcoholism often masks the findings; many of these patients are semiconscious, stuporous or near raving maniacs when admitted, and obtaining a history is impossible. A rapid examination will often reveal the classic Beck triad of low or falling arterial pressure, high or rising venous pressure, as evidenced by distended veins, and a quiet heart. Pulse pressure is low or unobtainable. Accurate localization of external wounds and plotting of presumed missile track often indicate probable cardiac injury. In gunshot wounds, particularly the perforating type, the bleeding is often not trapped in the pericardium but escapes into the adjacent pleural spaces, with no signs of Beck's triad obtainable. The indications for immediate thoracotomy are nevertheless clear and imperative for control of hemorrhage even though the heart may not be

TABLE 1

GUNSHOT WOUNDS OF THE HEART

Case No.	Year	Race and Sex	Age (yr.)	Weapon	Time from Wound to Admission	Time from Admission to Operation	Route in Hospital	Location of Wound	Type of Wound	Result	Other Injuries	Wound Entrance	Wound Exit	Tamponade	Comments
A1	1934	N, M	11	Rifle (22)	70+ min.	?	Emergency room, x-ray, operating room	Right ventricle	Laceration	Lived	?	Fourth intercostal space 3 cm. right of sternum	?	?	Discharged on thirty-fifth postoperative day
A2	1935	N, M	26	Pistol	80+ min.	?	Emergency room, operating room	Left ventricle	Penetrating	Lived	Left hemopneumothorax, left lung	Fifth intercostal space in left anterior axillary line	Embolus of bullet to iliac artery	Liquid	Discharged on forty-second postoperative day
A3	1942	W, M	58	Pistol	40 min.	10 min.	Emergency room, operating room	Right ventricle	Laceration	Lived	Left descending coronary vein and left lung	Third intercostal space in left midclavicular line	None; bullet not found even with x-ray films of entire body	Clotted	Discharged on twenty-fourth postoperative day; 2,500 cc. autotransfusion; alive in April 1957
A4	1943	N, M	23	Pistol (25)	65 min.	45 min.	Emergency room, operating room, x-ray, operating room	Right ventricle	Laceration	Lived	Left hemopneumothorax with sucking wound in chest, left lung	Fourth intercostal space in midclavicular line	Eighth intercostal space at posterior axillary line	Liquid	Discharged on thirtieth postoperative day; 1,200 cc. autotransfusion
A5	1950	W, M	15	Shotgun	5 hr.	90 min.	Emergency room, ward, x-ray, operating room	Right ventricle	Laceration (no repair required)	Lived	6 by 4 inch sucking wound, left anterior inferior chest, left lung	Left anterior lower chest	Multiple buckshot, left anterolateral lower chest	"Large," clotted	Discharged on twenty-sixth postoperative day
A6	1952	W, M	35	Pistol (32)	?	45 min.	Emergency room, operating room	Right ventricle and right auricle	Perforation	Lived	Diaphragm, left lung	Sixth rib at right sternal margin	Tenth intercostal space at left posterior axillary line	Clotted	Discharged on thirty-fifth postoperative day
A7	1953	N, F	43	Pistol (22)	?	30 min.	Emergency room, operating room	Left ventricle	Laceration	Lived	None	Lower sternum	Bullet in inferior posterior mediastinum	Clotted	Discharged on twelfth postoperative day; alive in July 1959; electrocardiographic evidence of infarction
D1	1935	N, M	43	Pistol (38)	Not operated, 15 min.		Emergency room, ward	Right ventricle	Perforation	Died (10 min. after admission)	Descending thoracic aorta, liver, diaphragm, large mediastinal hematoma (lower anterior portion)	Fifth intercostal space 4 cm. left of midline	Bullet in twelfth thoracic vertebra	Clotted (autopsy)	Died immediately following admission to ward

TABLE I (*Continued*)

GUNSHOT WOUNDS OF THE HEART

Case No.	Year	Race and Sex	Age (yr.)	Weapon	Time from Wound to Admission	Time from Admission to Operation	Route in Hospital	Location of Wound	Type of Wound	Result	Other Injuries	Wound Entrance	Wound Exit	Tamponade	Comments
D2	1937	N, M	24	Pistol (38)	Not operated (?)		Emergency room, ward	Right ventricle, left ventricle and septum	Perforation	Died (10 min. after admission)	Bilateral hemothorax (3,500 cc.) left arm, both lungs	Sixth intercostal space 14 cm. under left of midline	Bullet in right chest, fifth rib, 7 cm. right of sternum	"Large," liquid	Death from tamponade and hemorrhage
D3	1941	N, M	45	Pistol (38)	Not operated, 10 min.		Emergency room, ward	Right ventricle	Perforation	Died (10 min. after admission)	Diaphragm, stomach, spleen, left kidney and liver	Sixth intercostal space 1 cm. lateral at left sternal border	6 cm. to left of midline, twelfth rib	Clotted	Death from cardiac tamponade
D4	1941	N, M	30	Pistol (32)	Not operated (?)		Emergency room, ward	Left ventricle	Laceration	Died (10 min. after admission)	Contused pulmonary artery, contused left auricle, both lungs, left hemothorax (1,200 cc.)	Second intercostal space in left midclavicular line	Bullet in hilum, right lung	Clotted (300 cc.)	Death from tamponade and hemorrhage
D5	1941	N, M	24	Pistol (32)	20 min.	15 min.	Emergency room, operating room	Right ventricle and left ventricle	Perforation	Died (10 min. after incision made)	Left lung, left hemothorax (3,000 cc.)	Third intercostal space at left sternal border	Bullet lying free in pleural cavity	None	Death from exsanguinating hemorrhage
D6	1943	N, M	32	Pistol (38)	110 min.	80 min.	Emergency room, ward, x-ray, operating room	Right ventricle	Perforation	Died at surgery (5 min. after incision made)	Right hemothorax (1,000 cc.), right lung, right liver, right kidney, right hand	Supraxiphoid	Bullet subcutaneous at right posterior axillary line and eleventh rib	Clotted	Negative pericardiocentesis
D7	1943	N, M	27	Pistol (32)	70 min.	60 min.	Emergency room, x-ray, operating room	Right ventricle and left ventricle	Perforation	Died (24 hr. after surgery)	Right liver, compound fracture of right forearm, left tension pneumothorax, left hemothorax	At mid-xiphoid	Bullet in right liver	Clotted (250 cc.)	No autopsy, continued hemorrhage
D8	1943	N, M	39	Pistol (32)	75 min.	15 min.	Emergency room, operating room, x-ray, operating room	Left ventricle and left auricle	Perforation	Died at surgery (20 min. after incision made)	Both lungs, left pneumonary vein, left hemothorax	Just lateral to left nipple	Bullet subcutaneous just below spine at right scapula	Clotted	Autopsy: bilateral hemothorax (right, 1,400; left, 800)
D9	1946	N, M	35	Pistol (32)	30 min.	20 min.	Emergency room, operating room	Right ventricle and right auricle	Perforation	Died at surgery (20 min. after incision made)	Bilateral hemothorax (2,000 cc.), right middle lobe of lung	Second intercostal space, 2 cm. to left sternum	Through sixth rib at right mid-axillary line in subcutaneous tissues	Clotted	Death from cerebral anoxia

TABLE 1 (*Continued*)

GUNSHOT WOUNDS OF THE HEART

Case No.	Year	Race and Sex	Age (yr.)	Weapon	Time from Wound to Admission	Time from Admission to Operation	Route in Hospital	Location of Wound	Type of Wound	Result	Other Injuries	Wound Entrance	Wound Exit	Tamponade	Comments
D10	1947	N, M	36	Pistol	Not operated, 100 min.		Emergency room, operating room, x-ray, operating room, x-ray, ward	Left ventricle	Laceration	Died in ward (4 hr. after admission)	Left lung, left hemothorax (800 cc.)	1. 2 cm. above suprasternal notch 2. Third intercostal space at left midclavicular line 3. Point of left shoulder	Bullet at seventh intercostal space at posterior axillary line, subcutaneous; bullet at fifth intercostal space at left mid-axillary line, subcutaneous; bullet at left shoulder joint	None	Cardiac wound not diagnosed
D11	1954	N, M	33	Pistol (32)	80 min.	65 min.	Emergency room, operating room	Left ventricle	Perforation	Died at surgery (4 hr. after incision made)	Diaphragm, right liver, esophagus, left lung, ?inferior vena cava, left arm, right arm, both brachial arteries	Eighth rib at left posterior axillary line, multiple wounds of both arms and shoulders	Bullet in right lower quadrant of abdomen	None	3,500 cc. Autotransfusion 3,000 cc. Transfusion 3,000 cc. Dextran
D12	1954	W, M	43	Pistol (32)	110 min.	85 min.	Emergency room, operating room	Left ventricle	Laceration	Died on return to ward (9½ hr. after surgery)	Multiple wounds in small bowel (midbowel resected)	1. Sixth intercostal space at left sternal margin 2. Third intercostal space at left sternal margin 3. Sixth intercostal space at right sternal margin	1. Left anterior axillary line at costal margin 2. Bullet subcutaneous at seventh intercostal space at left posterior axillary line 3. Bullet subcutaneous below left iliac crest	None	1,150 cc. Autotransfusion 5,000 cc. Blood transfusion
D13	1955	W, M	39	Pistol (38)	63 min.	20 min.	Emergency room, operating room	Right ventricle and septum	Perforation	Died at surgery (20 min. after incision made)	Left lung	Third intercostal space at left sternal margin	Over tip of left scapula	Clotted	Cerebral anoxia

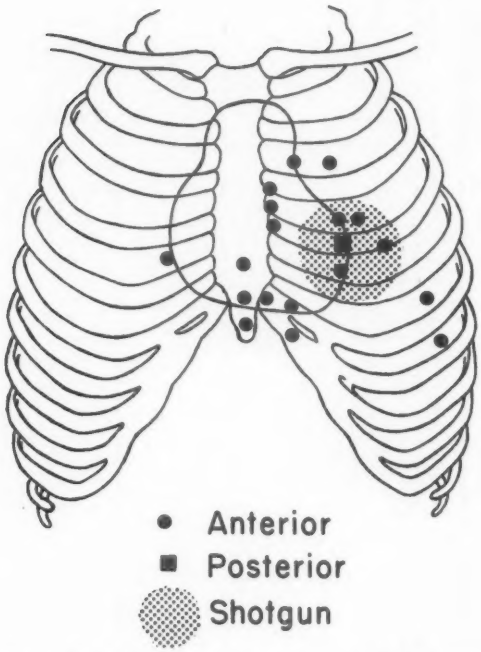

FIG. 1. Sites of entrance of gunshot wounds of the heart.

damaged. Death may result from an injured internal mammary, intercostal or other major blood vessel, including the aorta, as rapidly as from an injured heart.

PATHOLOGY

The pistol was the most common weapon for these wounds, being the cause seventeen times of 19 recorded; the rifle and shotgun each were responsible one time. The sites of entrance were mostly over the left anterior and medial chest from the second to seventh ribs (Fig. 1), but a few were in the upper abdomen and right chest. There were eight lacerations with non-penetration of the heart chambers (Table II), four involving the left ventricle and four the right ventricle. There were twelve perforating wounds, two of the left ventricle, four of the right ventricle, three of both ventricles, one of both the left ventricle and auricle, and two of both the right ventricle and auricle. Tamponade was present in ten of twelve perforations (Table III) and five of seven lacerations, or 79 per cent of the wounds. Tamponade with clotting occurred in seven of twelve perforations and four of seven lacerations, or 58 per cent of the series. Injury to coronary vessels was noted in only one instance, the left descending vein. Injuries to other organs were usual, especially when heart perforations occurred. One or both lungs were usually injured with resultant massive unilateral or bilateral hemothorax. Both lungs were perforated in two patients, and both died. Survival with injuries to organs other than the heart and lungs is not recorded in this series.

Multiple organs, other than the heart and lungs, were involved in seven patients, in four by a single missile and in three by three missiles. Among these injuries are one involving the diaphragm, liver, stomach, spleen and kidney; another involving a pulmonary artery; one involving the esophagus and inferior vena cava; another with multiple bowel perforations requiring extensive bowel resection, and another with lacerations of the descending thoracic aorta, the liver and diaphragm. Deaths were usually due to rapidly exsanguinating hemor-

TABLE II
GUNSHOT WOUNDS OF HEART (1934 TO PRESENT)

	Operated				Not Operated				Totals		
	Laceration		Perforation		Laceration		Perforation				
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	All
Right ventricle	4			2				2	4	4	8
Left ventricle	1	1	1	1		2			2	4	6
Right ventricle and left ventricle				2				1		3	3
Right ventricle and right auricle			1	1					1	1	2
Left ventricle and left auricle				1						1	1
Totals	5 (83%)	1 (17%)	2 (22%)	7 (78%)		2 (100%)		3 (100%)	7 (35%)	13 (65%)	20

rhage into the pleural cavities or abdomen or to cardiac tamponade often found clotted at operation or autopsy.

TREATMENT

All seriously injured patients are immediately moved from the emergency rooms to the operating rooms where they are quickly re-evaluated and the decision as to need for operation is quickly made. An operating room is set up twenty-four hours a day with sterile instruments and linens already laid out and covered with sterile drapes which can be quickly removed. We can thus begin the operation within five minutes of the patient's admission to the operating room. We insist that the senior surgical resident on duty (usually a fourth-year resident) proceed immediately as soon as he is reasonably sure of damage to the heart, cardiac tamponade or evidence of massive hemorrhage. The staff man is immediately alerted, but since immediate control of the hemorrhage and release of tamponade is essential often in minutes he only exceptionally arrives before the situation is under control. Intravenous fluids, dextran and blood are immediately given by cutdown if necessary, but should not be allowed to delay operation as they are of little value preoperatively in tamponade and only of questionable value before control of massive bleeding. We have found pericardiocentesis of only occasional benefit since the tamponade is often clotted or bleeding is into the pleural space without tamponade; however, it may prove life-saving to tide the patient over while preparations are made for operation, particularly when the diagnosis is in doubt.

Speed in preparing for operation is essential. The scrub team uses the rapid three-minute pHisoHex® or septisol scrub and the patient should be similarly prepared simultaneously.

Anesthesia usually presents few problems. Most of these patients are comatose and no premedication is used. If the patient is awake, an endotracheal tube is inserted with topical anesthesia (usually 1 per cent Pontocaine®) instilled by transtracheal needle puncture or, if comatose, without difficulty or need of anesthesia. Oxygen is then given until the patient responds, with cyclopropane added as necessary to keep him in a light plane of anesthesia.

The chest is rapidly opened through the

TABLE III

TYPE OF TAMPONADE IN GUNSHOT WOUNDS OF THE HEART (TWENTY WOUNDS)

	Operated				Not Operated		
	Clotted	Liquid	None	Unknown	Clotted	Liquid	None
Right ventricle	Laceration (Perforation)*	Laceration	(Perforation) (Laceration) (Perforation)	Laceration	(Perforation) (Perforation)	(Perforation)	(Laceration)
	Laceration (Perforation)	Perforation			(Laceration)		
Left ventricle	Laceration						
Right ventricle and left ventricle	(Perforation)						
Right ventricle and right auricle	(Perforation) Perforation						
Left ventricle and left auricle	(Perforation)						

* Parentheses indicate death.

fourth intercostal space anteriorly with the patient in the supine position; if the major damage appears to be in the right chest, then the right fourth intercostal space is used. Occasionally it will be necessary to divide the fourth and fifth costal cartilages but hardly ever to remove the fourth rib itself to obtain additional exposure. Damage to the pleural space is quickly assessed, and if extrapericardial hemorrhage is found it is temporarily controlled. Cardiac tamponade is evidenced by a bluish distended pericardium with very weak or no contractions of the heart. The pericardium is then opened vertically 2 to 3 cm. anterior to the phrenic nerve and the tamponade evacuated. Liquid blood both from the pleural space and pericardium is often collected, filtered and used as an autotransfusion if other blood is not immediately available. With release of the tamponade the heart quickly resumes its normal activity, and brisk bleeding usually makes locating the heart wound no problem. Exposure of the posterior heart or rotation up to 90 degrees is facilitated by a heavy figure-of-eight traction suture through the apex of the ventricle.

With the injury located, hemorrhage is usually easily controlled by finger pressure until actual repair of the wound under the finger with interrupted No. 2-0 permanent sutures is accomplished or until the proper placement of crossed traction sutures is secured to control hemorrhage pending definitive repair. Care should be taken to avoid penetrating the endocardium with the suture needle, and the sutures should be tied only tight enough for hemostasis to avoid strangulation of the heart muscle. Large coronary vessels are avoided by means of mattress sutures placed deep to the vessels. To the present, we have ligated rather than anastomose bleeding coronary vessels. The pericardium is left wide open and the chest wall closed with chest tubes through separate stabs laterally and inferiorly.

Postoperatively these patients are managed as myocardial infarctions with the exception that anticoagulants are not given. Oxygen, additional blood, modified bedrest and narcotics for relief of pain are used as necessary. All these wounds are considered contaminated and antibiotics are given accordingly. Serial electrocardiograms are made on each patient and usually show changes consistent with infarction. Many return to normal within a few days or weeks but others show permanent damage.

COMMENTS

Considerable controversy has arisen in recent years over the question of immediate intervention [2–5] versus pericardiocentesis [6–9] with later more deliberate exploration if needed. Our experience indicates that gunshot wounds are fraught with far greater hazard than those due to sharp instruments. Nonoperative management in our hands has met with 100 per cent mortality, while 47 per cent of those who were operated upon have survived. We have not been impressed with the value of continuing to pour blood into a "bottomless bucket," so to speak, as has been the case with most of our patients with massive hemorrhage. Furthermore, nine of our thirteen deaths included multiple sites of extracardiac massive hemorrhage; these areas are obviously not amenable to control by pericardiocentesis. We believe that only surgical control of bleeding points offers the maximum possibility of survival.

Rapid bleeding into the pleura or pericardium often results in clots since the agitation of the lungs or heart does not adequately defibrinate the blood. Only with relatively slow bleeding does sufficient defibrination occur to provide easy aspiration of liquid blood. Rapid release of tamponade, particularly if clotted, can only be accomplished by operative means. We have also noted, as did Maynard [4], that even with the pericardium directly exposed, needle aspiration may not be successful. One should remember that a negative pericardiocentesis may well lull one into a false sense of security particularly if the blood is clotted. Delayed hemorrhage from blowout of a clot has been reported [10,11]. The possibility of late constrictive pericarditis as a result of organization of unaspirated hemopericardium is a question as yet unanswered [12,13] and presently under investigation in our research laboratory.

It is our impression that we may be seeing these patients earlier than is the case in most reported series, for we are fortunate in having a very efficient police ambulance service highly trained in first aid patrolling in cars or station wagons quickly adapted to the rapid transport of seriously injured patients. We have provided in our operating suite maximum facilities

nd personnel constantly and immediately vailable for the treatment of shock and rapid reparation of the patient for operation.

There is no doubt in our minds that patients een within a matter of minutes following gun- hot wounds of the heart are far better handled y immediate operation. As surgeons, we vastly refer the scalpel and the ligature for the con- rol of hemorrhage. The possibility of failure of ericardiocentesis and the likelihood of addi- ional extracardiac bleeding vessels together nake us reluctant to accept any other policy han direct surgical exposure and ligature of he bleeding vessels. We believe that this will offer our patients their greatest chance for survival. We further believe that our results in very early gunshot wounds of the heart justify this conclusion.

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DISCUSSION OF PAPERS BY DRS. MORRIS, BEALL, ROOF AND DE BAKEY; MARTIN AND SCHENK; AND RANSDELL AND GLASS

R. J. Noer (Louisville, Ky.): Drs. Ransdell and Glass have emphasized primarily the need for differentiating between gunshot wounds and stab wounds. There is no question but that many patients with small stab wounds will live for a considerable length of time, and some of them can be treated by pericardiocentesis.

The gunshot wound is a much more severe wound. It is usually associated with a greater degree of trauma and a high incidence of injury to vessels other than those involved in cardiac injuries, as the authors have shown.

We believe that in Louisville we see many patients with gunshot wounds at the hospital earlier than most have the opportunity to because we have a very efficient police zone. Dr. Ransdell checked the police records and found that on the average these patients are in the operating room within about forty-five minutes of injury to the heart. This is a remarkably short time, and we believe that perhaps we are seeing many patients who die before reaching the hospital in other areas. We believe that the need for exploration is emphasized by the high incidence of extracardiac trauma as well as that severely produced by the gunshot wound itself.

C. G. Johnston (Detroit, Mich.): In regard to the paper by Dr. Morris et al., I have two or three questions.

One is in relation to spasm. Were these patients actually explored and, if so, what was done about spasm? Was the vessel opened to see that constriction was not due to subintimal injury? I think we have become alerted to the fact that a hematoma in the region of vessels of any size must be explored, and I am sure this is one reason why more of these procedures are being performed.

I would like to ask Dr. Morris to comment on the use of autografts, especially in the femoral vessels. This is an excellent material to use, and I think it is something we should not lose sight of, for many times a vein graft does very well with little trouble.

The paper by Drs. Ransdell and Glass was very interesting. Several things have come to light in relation to gunshot wounds of the heart. Such patients usually die before they reach medical aid, generally from marked loss of blood. Sometimes

they have pericardial tamponade, but usually the cause of death is loss of blood. I have been somewhat afraid of aspirating patients even with stab wounds, although we do support them with palliative therapy for a while. We have had two who have done well for three or four days, and then have blown a clot and died suddenly. I think Dr. Noer's set-up is excellent. The diagnosis is obvious and the management is quite clear. Prompt action is required in these patients to prevent death from exsanguination.

E. R. MAURER (Cincinnati, Ohio): My comments will be limited to the paper by Drs. Martin and Schenk. In June 1958 Dr. Mendez, my associate, and I published in the *Journal of Angiology* the results of our experimental physiologic studies on the cardiovascular dynamics in pneumopericardium and hydropericardium. Mongrel dogs weighing 12 to 15 kg. were used in these experiments. Vascular pressure changes from the aorta, the right auricle, the left auricle, the left superior pulmonary vein and the coronary sinus were electrically monitored with Spatham strain gauges.

A needle with a specially devised plastic flange was used for leakproof delivery of air or saline into the pericardial sac at a preselected rate under constantly measured pressures. From these experiments the following observations were made. An average pressure of 16 to 20 cm. of water produced a prompt fall in the outflow tract or arterial pressure. I think it is perfectly obvious that the most significant change, however, as pointed out by Dr. Martin, was that preceding the fall in arterial pressure there is a preliminary rise in the venous pressure.

We were particularly interested in what happens to the auricle pressure on the left side. There is very little change as the air is injected into the pericardial sac.

The rate of instillation of air was the most important factor in the production of these alterations in arterial and venous pressures.

A catheter in the coronary sinus showed absolutely no change. Again there was a fall in the arterial pressure.

On the basis of these experiments we were able to develop what we thought was a simple, safe technic for the introduction of air into the pericardial sac for diagnostic purposes in the human. This technic was applied in a series of patients in the preoperative differential diagnosis of paracardiac, cardiac, pericardial and contiguous diaphragmatic lesions.

The use of air in the pericardial sac as an elective diagnostic maneuver, I think, has not been done in the past. These experiences were presented before the American College of Chest Physicians in 1957. A diagnostic pneumopericardium in a patient who had what originally appeared to be a large cardiac silhouette proved to be a tumor, which was removed.

Another patient was sent to us consistently with a diagnosis of mediastinal tumor. No murmurs were audible over the heart. She did have an evanescent murmur on occasion which did come and go. An angiocardiogram was uninformative. Air injected into the pericardium demonstrated the mediastinal density was an enlarged auricle, not a tumor. From these examinations it was determined that the patient had mitral stenosis for which she was subsequently operated upon.

Still another patient had a shell fragment in the vicinity of the diaphragm, pericardium and heart. Accurate localization was impossible. A tube was passed into the stomach, air was instilled and the fragment was found to be definitely unassociated with the diaphragm. A diagnostic pneumopericardium showed unequivocally that the shell fragment was in the heart. The fragment was successfully removed.

G. C. MORRIS, JR. (closing): Two aspects of the management of arterial injuries of great importance, as indicated by Dr. Johnston, are the management of local spasm and the selection of grafts. With reference to spasm, we believe that any injured patient with absent peripheral pulses should undergo exploration of the artery in the area of the injury. After the artery is exposed, if there is no pulse distal to the area of injury, the artery should be opened because only by arteriotomy can one delineate spasm from intimal tear with dissection.

In viewing our series in retrospect, I believe we could have used about half the number of grafts that were employed. Vein grafts are certainly superior to homografts, but so are dacron grafts which are more readily available.

W. G. SCHENK, JR. (closing): For those who are statistically inclined, the dark line on the scattergram (Fig. 5) is not merely a visual guess as to what we would like the trend to be, but a calculated linear regression line with a P value of less than 0.001.

In regard to the pulse rate, the conventional bradycardia described in tamponade was seen only terminally, not sequentially and progressively. Therefore, it was not of value in determining the degree of vascular impairment in this preparation. Most often the pulse rate remained relatively unchanged through the course of the experiment; hence, with a constant pulse rate and a falling cardiac output, a progressive reduction in stroke volume was indicated probably due to inadequate diastolic filling of the cardiac chambers. The paradoxic pulse characteristic of clinical tamponade would probably not be seen in this experimental preparation, of course, since the thoracic cavity was open.

In regard to the pulse-pressure; this quantity remained stable as long as the mean pressure remained stable and then narrowed as the mean pressure fell abruptly. Thus, this value also was not of much help in determining the circulatory impairment under these experimental conditions.

We do not delude ourselves into the belief that these experimental findings can be transferred without modification to patients, but we think they do indicate clearly the type of observations we must make in patients if we are to document more accurately their moment-to-moment hemodynamic alterations.

It is easy to recognize the problem when the classic Beck's triad is present. Our aim has been to find some change preceding the onset of the classic triad which might enable earlier operative management.

H. T. Ransdell, Jr. (closing): I would like to pass on a small hint. We have found our Police Department extremely helpful, particularly in obtaining a history on the patients. The coroner's records and homicide investigations, made even though the patient does not die, have been excellent histories. You might request your department's help in some future studies.

Safe at Home

JOHN H. POWERS, M.D. AND S. RICHARD PROTHERO, M.D., *Cooperstown, New York*

From the Department of Surgery, The Mary Imogene Bassett Hospital, Cooperstown, New York. This study was supported in part by a grant from the Division of Special Health Services, Accident Prevention Program, United States Department of Health, Education and Welfare.

ACCIDENTS in the home constitute a major threat to the lives of 170,000,000 Americans. In 1958, 27,000 people were killed, 110,000 were permanently disabled and nearly 4 million more were temporarily incapacitated because of injuries which occurred while they were "safe at home" [1]. Ignorance of the environmental perils of domestic life, faulty construction of buildings and equipment, failure to correct hazards which do exist, carelessness, poor judgment and fatigue are largely responsible for such tragedies.

The dangers of industry have been recognized for many years, and definitive measures have been instituted for the promotion of safety. Both the number and rate of fatal and nonfatal industrial accidents have dropped significantly within the past three decades. Formal legal restrictions for the promotion of individual safety are impossible in domestic life, and the actual number of deaths from accidents in the home has increased during this same period of time [1].

Estimates indicate that 90 per cent of all accidents are preventable [2]. Since shelter of some sort is an essential of living, families must learn that safety in the home is an obligation of every member of the household. To accomplish this purpose, education is of primary and paramount importance. Education for the prevention of accidents in daily living should rest largely with the medical profession. Successful planning for such preventive medicine in the field of trauma must include specific knowledge of the facts which relate to accidents.

Therefore, we wish to present data relative to home accidents as they occurred in rural Otsego County, New York from 1946 through 1950, and 1953 through 1957. As a result of these mishaps, 541 patients were admitted to The Mary Imogene Bassett Hospital in Cooperstown. There were 274 patients treated in the first five-year period and 267 in the second. The two groups will be considered collectively for statistical review with one exception. Only patients whose injuries necessitated hospitalization have been included in the survey.

DATA

Age Incidence. Infants and children were injured at home from birth to five years of age with far greater frequency than during any other half decade of life. (Fig. 1.) The majority of such accidents occurred during the second year of life "when the infant is still largely dependent on his parents for protection and yet is beginning to acquire minimal self reliance and some freedom from constant parental supervision" [3]. Prolonged protection, supervision and discipline (even to the fourth and fifth years) are essential. This must continue until children learn to appreciate and recognize the hazards to which they are constantly exposed.

A sustained reduction in the incidence of injury is maintained from the end of the first decade of life to the middle of the seventh. The curve rises rather sharply after this, due in large part to the relative helplessness of elderly persons and their increased susceptibility to falls and burns.

Data on *fatal* home accidents in New York State from 1949 to 1957 [4] indicate that men die of injuries somewhat more often than women until after the age of seventy when accidental death at home is much more common among females. The incidence in this age group is greater than during the first half decade of life (Fig. 2) despite the frequency of nonfatal trauma during infancy and childhood.

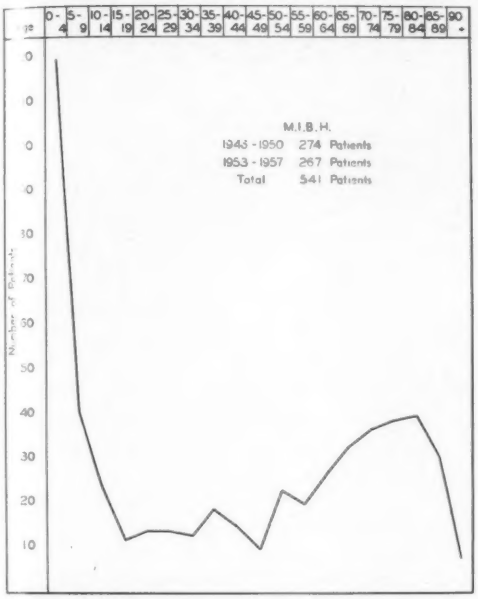

FIG. 1. Graphic representation of the age distribution by half decades among 541 patients injured while "safe at home."

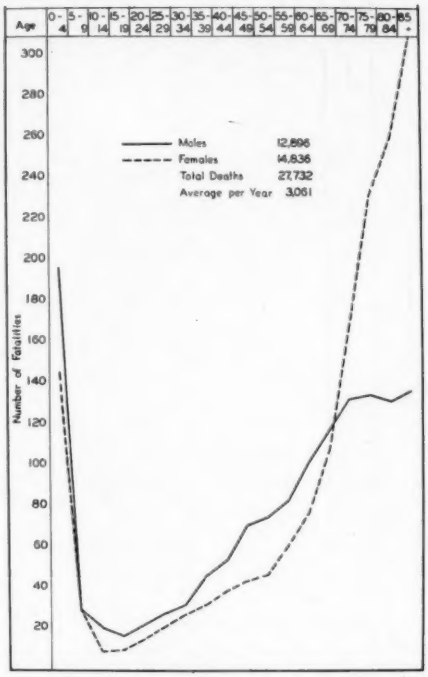

FIG. 2. Average annual distribution (by age and sex) of fatal accidents in New York State during the years 1949 through 1957.

Seasonal, Weekly and Daily Incidence. The incidence of all rural accidents rises rapidly during the summer months and falls abruptly with the tourists' departure from the highways, completion of the harvest and the return of children to school [5]. The seasonal distribution of accidents which occur only at home follows the same general pattern. (Fig. 3.) The sustained peak during July and August is due in large part to unsupervised play of children during the long summer vacation and to the urban and metropolitan tourist's lack of awareness of the hazards which surround him (old buildings, trees, machines and animals) in a rural area. During autumn, winter and spring, the incidence of home accidents remains quite constant in Otsego County.

No significant variation in the weekly distribution of home accidents is indicated except a probable increase on Sunday (Fig. 4) perhaps due to father's presence at home, cutting the grass, tinkering with unfamiliar equipment or performing some unusual task.

However, there is a very impressive peak in the distribution of home accidents throughout the day. One hundred thirty accidents (31 per

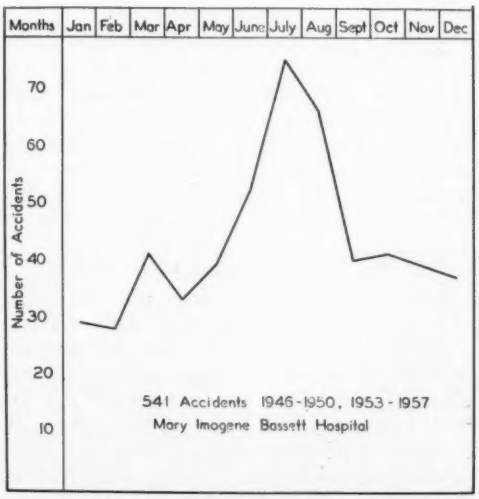

FIG. 3. Composite curve representing the seasonal distribution of home accidents (1946 through 1950, 1953 through 1957).

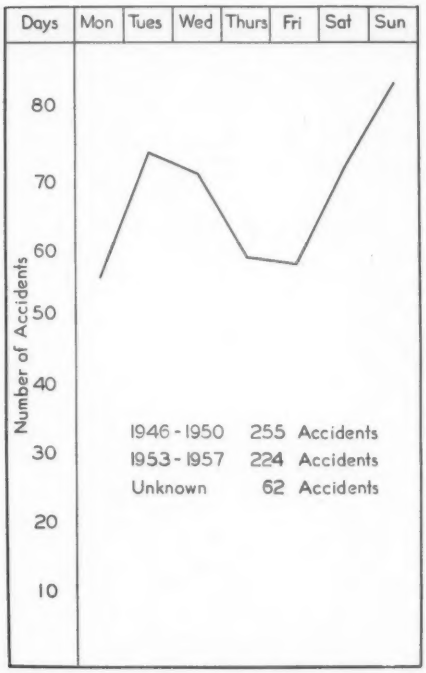

FIG. 4. Graphic representation of the distribution of home accidents throughout the week.

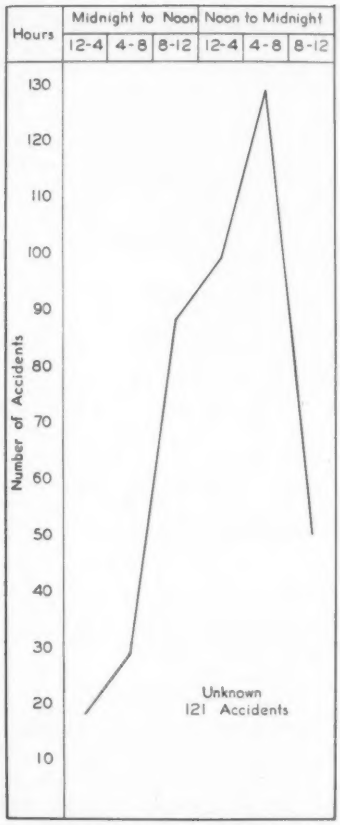

FIG. 5. Daily distribution of accidents at home. The peak between 4 o'clock in the afternoon and 8 o'clock in the evening is impressive.

cent of those for which the hour of occurrence could be accurately determined) occurred between 4 o'clock in the afternoon and 8 in the evening. (Fig. 5.) Unsupervised play after school, carelessness due to fatigue at the end of the day and poor vision in the aged during dusk of twilight are doubtless responsible for many of these accidents. Despite the tendency of elderly people to fall at night, accidents are quite infrequent between midnight and 8 o'clock in the morning. Then the home bustles with activity in preparation for work and school. During these hours both parents and children are rested, and parents are available to furnish help and guidance to their children.

Etiologic Agents. Two factors are involved in all accidents—a motivating activity and an etiologic agent. In a previous review of 1,779 rural accidents of all types [5], the three most common motivating factors were motoring, domestic activities and farming. (Table 1.) In the present series of 541 home accidents, the over-all motivating activity was, of course, domestic life.

There were many etiologic agents, but falls were by far the most common (Table 11) and were responsible for nearly two-thirds of all accidents. Among elderly people, falls on the same level were somewhat more frequent than those on stairs. The next most common injury was children falling at play, followed by those occurring when aged persons were getting into or out of bed or chairs.

Fire and hot water are particularly hazardous during infancy and childhood. Burning leaves and bonfires attract children and often cause death or permanent injury and deformity.

The inhalation or ingestion of foreign irritants (such as pennies, peanuts, marbles, buttons, kerosene, gasoline, cleaning fluid or furniture polish) may cause fatal obstruction of the tracheobronchial tree, pneumonia, pul-

TABLE I*

MOTIVATING ACTIVITIES RESPONSIBLE FOR 1,779 RURAL ACCIDENTS

Activities	Patients	
	No.	Per cent
Motoring	516	29.0
Domestic activities	365	20.5
Farming	345	19.4
Other occupations	180	10.1
Sports	170	9.6
Miscellaneous activities	203	11.4
Total	1,779	100.0

* FROM: POWERS, J. H. [5].

monary abscess, esophagitis or gastritis. Over four-fifths of all fatal accidental poisonings occur at home. Barbiturism is most frequently recorded, but quantities of aspirin (particularly the sugar-coated variety) or petroleum products are more frequently ingested by children, especially toddlers.

Bites by animals, both wild and domestic, may be very dangerous in an area where rabies is endemic, as it has been in central New York during the past fifteen years. Several children and adults have received the Pasteur treatment at The Bassett Hospital because they were bitten by rabid dogs, cats, foxes and horses. In only one patient, an elderly woman, did clinical rabies develop; she had been bitten in the wrist by her own cat and did not seek medical aid until two weeks after the injury. Therapy was then ineffective.

Location. For the purpose of comparative study, the areas in the home where accidents were most prone to occur are tabulated individually for each five-year period. (Table III.) Twenty-one per cent of all the accidents in each series occurred in the yard. Stairs were the greatest hazard within the house, often because of the absence of hand rails, inadequate lighting, scatter rugs at the top or bottom, or toys and playthings left on the treads. The close correlation between the frequency of accidents in the kitchen, bedroom, living room and bathroom in each series is interesting and significant.

Classification of Injuries. One thousand fifty-one injuries (classified according to the "Standard Nomenclature of Disease") were suffered by these 541 patients. Multiple injuries are more common in a patient who is injured in a motor vehicle accident than in

TABLE II

ETIOLOGIC AGENTS RESPONSIBLE FOR 541 ACCIDENTS AT HOME

Agents	Accidents	
	No.	Per cent
Falls	334	61.7
Excessive heat or cold	55	10.2
Cutting or piercing instruments	44	8.1
Foreign bodies	31	5.7
Foreign fluids	17	3.1
Animal bites	14	2.6
Crushing instruments or machines	10	1.9
Blows	9	1.6
Firearms	6	1.1
Falling bodies	5	1.0
All others	16	3.0
Total	541	100.0

TABLE III

AREAS WHERE ACCIDENTS OCCUR AT HOME

Location	Accidents			
	1946–1950		1953–1957	
	No.	Per cent	No.	Per cent
Yard	58	21.2	57	21.7
Stairs or steps	43	15.7	31	11.6
Kitchen	40	14.6	41	15.3
Bedroom	25	9.1	26	9.7
Living room	17	6.2	11	4.1
Bathroom	11	4.0	9	3.3
Porch	9	3.3	4	5.2
Dining room	7	2.5	0	0.0
Cellar	4	1.5	9	3.3
Garage	4	1.5	4	1.5
Roof	4	1.5	4	1.5
Other areas	5	1.8	8	3.0
Unknown	47	17.1	53	19.8
Total	274	100.0	267	100.0

TABLE IV

ACCIDENTAL INJURIES SUSTAINED BY 541 PERSONS

Classification	Injuries	
	No.	Per cent
Fractures	383	36.4
Burns	169	16.1
Contusions	87	8.3
Lacerations	71	6.7
Poisonings	39	3.7
Dislocations	36	3.4
Concussion of brain	31	2.9
Abrasions	30	2.8
Divisions or amputations	29	2.8
Foreign bodies	21	2.0
Incised or punctured wounds	13	1.2
Animal bites	11	1.1
Gunshot wounds	6	0.6
Miscellaneous injuries	125	11.9
Total	1,051	99.9

these injured at home [6]. Fractures were most common and comprised 36 per cent of the total number. (Table IV.) Burns were next in order of frequency; three patients died of burns which involved 70 per cent or more of the body surface. Contusions and lacerations were next. Sixty patients ingested or inhaled poisonous liquids, gases or foreign bodies. Thirty-one had concussion of the brain, eleven were bitten by animals, and only six were accidentally shot (none fatally). The number and percentage of dislocations, abrasions and other common injuries are tabulated in Table IV.

Analysis of Fatalities. Eight deaths occurred among the 274 patients injured from 1946 through 1950, and six of the 267 patients in the later group (1953 through 1957) died. The total mortality rate was 2.6 per cent. These fourteen fatalities are tabulated (Table V) according to the precipitating agent responsible for the accident, the major injuries sustained and the chief cause of death. Falls were responsible for nine of the fatal accidents, extensive burns for three, the ingestion of furniture polish for one and a cat bite for one. Fractures were the most common injuries.

Many elderly patients died of the complications to which old age is heir—bronchopneumonia, cerebral hemorrhage, pulmonary embolism, edema and cardiac decompensation.

TABLE V

ANALYSIS OF FOURTEEN DEATHS FROM ACCIDENTS IN THE HOME

Data	No. of Patients
Principal cause of death:	
Pneumonia	5
Irreversible shock	2
Rabies	1
Pulmonary embolism	1
Pulmonary insufficiency	1
Cerebral hemorrhage	1
Cerebral edema	1
Ventricular fibrillation	1
Carcinomatosis	1
Responsible etiologic agents:	
Falls	9
Excessive heat (hot water and fire)	3
Animal bite (cat)	1
Foreign fluid (furniture polish)	1
Major injuries:	
Fractures	7
Multiple burns	3
Lacerations	2
Poison	1
Contusions	1

Six of the patients were eighty-five years of age or older, three were between seventy and eighty, one was sixty-two, another was twenty-three, one child was four years of age, and two infants were eleven and eighteen months of age, respectively.

SUMMARY

Thousands of Americans are killed annually, many thousands are permanently disabled, and millions are injured temporarily while "safe at home." Such accidents occur most commonly during infancy, early childhood, and old age.

In rural Otsego County they follow definite diurnal and seasonal patterns with daily peaks between 4 and 8 o'clock in the evening and annual peaks during the summer months of July and August.

Falls are responsible for nearly two-thirds of such tragedies; fire, hot water, foreign bodies and poisons for many others.

Accidents in the yard are frequent; within the house, stairs are most dangerous, followed by the kitchen, the bedroom, the living room and the bathroom.

Fractures comprise over one-third of the total injuries.

The mortality rate among 541 patients was 2.6 per cent. Death in many instances was not due to the injury but to complications to which old age is heir.

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Cross Chest Flap Grafts

WILLIAM L. WHITE, M.D., *Pittsburgh, Pennsylvania*

From the University of Pittsburgh School of Medicine Pittsburgh, Pennsylvania.

IN many severe traumatic disabilities of the hand the primary step in reconstruction must be replacement of scarred and ischemic skin defects by flap grafts. Generally these flaps have been constructed on the abdominal surface and applied directly to the recipient sites on the upper extremities. It is well known that the preparation, construction, application, separation and remolding of these pedicle grafts is costly in terms of time, patient comfort and expense [3]. In an attempt to minimize these deterrants, flaps have been designed to fit the recipient sites when the forearm lies across the lower chest and upper abdomen with the elbow flexed at right angles. This position has been used by many [2,9,10]. It has been the purpose of this study to utilize the cross chest position unless specifically contraindicated. This experience has revealed that the lower anterolateral chest surfaces and the upper abdomen provide excellent tissue for transfer. In comparison with the abdomen, the skin is more pliable, the fatty layer is thinner, the vascularity is abundant and diffuse, and the surrounding tissues are more elastic. Often these characteristics permit elevation and application of grafts in one stage and closure of donor defects without free grafts. In addition, the thinner tissue resembles that of the hand and forearm and allows more accurate planning and fitting so that subsequent shaping and defatting may be unnecessary. The cross chest position of the forearm adds greatly to patient comfort, mobility and cleanliness. In many instances these patients may be discharged from the hospital before separation of the flap, to be followed up as outpatients.

INDICATIONS

Flap grafts of skin and subcutaneous tissue retain their blood supply through their bases. With this independent viability these transfers make no demand upon the recipient sites beyond their ability to heal. This method of skin replacement restores those protective qualities of normal skin which are essential to reconstruction of underlying structural and functional elements. These flaps not only provide adequacy of coverage but also may materially improve an impoverished circulation. The increased blood flow is attributed to release of contracture and introduction of tissues with sympathectomized vascular channels. Reduction of edema by improved lymph flow is an additional benefit of these procedures.

These features of pedicle transfer indicate their range of usefulness. Since most cutaneous defects of the upper limb may be repaired adequately with local tissue or free grafts, pedicles generally are relegated to reconstruction of extensive, deep and ischemic lesions [1,2,7]. These incapacitating defects are almost always accompanied by an element of desperation which may crowd the bounds of good judgement. The feasibility of flap grafting should not distort the potentials of functional reconstruction.

Occasionally flaps are needed in acute injuries to protect and preserve essential functional parts.

Cross chest flaps can be utilized to resurface almost any defect of the upper extremity. They are particularly well suited for application to the hand by virtue of their pliability and thinness. A factor of cosmetic importance is the relative lack of hair in this area [5]. All flap grafts to the upper extremity should be lined on the exposed surface with free skin grafts or the flap should be tubed [3,6,9]. This avoids the undesirable effects of an open wound in a hand already incapacitated by trauma [2].

CONTRAINDICATIONS

Flap grafts to the upper extremities are never procedures of election but rather those of

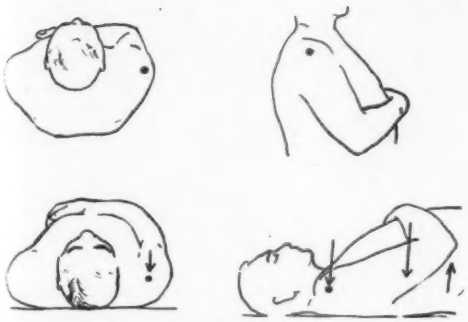

FIG. 1. In an obese or emphysematous patient, the cross chest position is easily attained with the body upright. However, upon reclining, the chest cage is thrust upward and the shoulders drop. This produces tension on an attached flap. *Upper left*, standing (from above). *Upper right*, standing (from the side). *Lower left*, recumbent (head view). *Lower right*, recumbent (side view).

necessity. The method is too cumbersome for replacement of simple skin defects in which local tissue, split grafts or full-thickness grafts would suffice. Because of this they are generally contraindicated in acute injuries. Flaps are also contraindicated in open lesions because of sepsis [9]. It is preferable to obtain healing of a denuded surface by thin free grafts and if necessary apply a pedicle later.

The cross chest position is contraindicated if large tubes are to be applied to the terminal aspect of the hand. These tubes are best obtained from the lower quadrants of the abdomen.

The most disturbing problem encountered with this position is that of increased chest bulk. This may be due to obesity but more often is due to pulmonary emphysema. In these barrel-chested persons it is relatively easy to place the arm across the trunk if the patient is standing or sitting. However, upon recumbency, the rib cage is pushed up and the shoulders drop. If a flap has been applied this results in pull and tension on the pedicle. (Fig. 1.)

In females, small donor defects located in the inframammary region can be closed without disturbance. However, closure of large donor sites in this area may displace the breast downward. In these instances it would be preferable to use the lower abdomen.

DONOR SITES

Lower anterolateral chest flaps are based laterally on the intercostal vessels and the

FIG. 2. Looseness of the skin of the lower chest is demonstrated.

thoracoepigastric system. The skin in this area has great mobility as it moves over the flare of the lower rib cage. (Fig. 2.) In these areas there are relatively few vascular channels penetrating to the underlying tissues. This indicates a diffuse self-contained vascular system which makes this tissue particularly well suited as donor sites for flap grafts. The anterior chest and upper abdominal flaps are based either inferiorly on the vascular area about the umbilicus or may be based above on the internal mammary and the superior epigastric systems. The skin in this area includes the linea alba about which the collateral blood supply is poor.

Selection. The selection of the pedicle site should depend upon the location, size and nature of the recipient defect with due consideration to patient comfort, ease of application, availability of skin and cosmesis. Donor sites for the cross chest position may arise in three areas: from the opposite side, the anterior torso and the same side.

Contralateral chest flaps: Flaps originating on the opposite anterolateral chest are ideally suited to provide skin areas not exceeding 16 square inches to the digits, palm, dorsum of the hand and occasionally the wrist. As indicated previously herein, closure of these defects is possible because of the laxity of the surround-

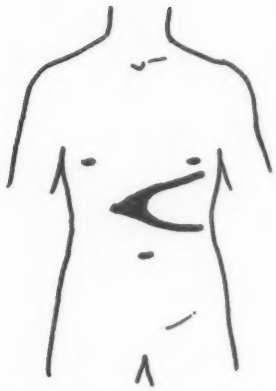

FIG. 3. Wedge of tissue extending across the midline removed and discarded to facilitate closure of the donor defect.

ing tissues. Better cosmetic closure may be obtained in these laterally based flaps if a wedge is resected, extending beyond the midline. (Fig. 3.) It is unwise to use this tip of tissue for transfer since collateral blood supply is poor. The ability to close the donor defects without skin grafting permits rotation of flaps at their base through a range of 180 degrees [2]. (Fig. 4.) Rotation is accomplished by extending the upper or lower limbs of the incision. If the upper incision is carried laterally for a distance equal to the width of the flap, it may be rotated upward upon closure. Conversely, if the lower limb of the incision is extended, the rotation is downward. Since there is relatively little fat present about the lower chest, the flaps may be tubed without thinning. Due to the excellence of vascularity, these flaps seldom have to be delayed. With the arm in the cross chest position, external fixation may be pro-

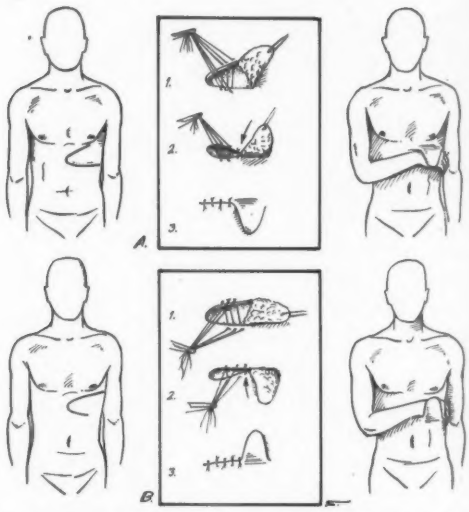

FIG. 4. By extending the limbs of the flap incision, it is possible to rotate these pedicles through 180 degrees. This provides ease of application.

vided by adhesive tape and elastic bandage if the patient is slight. The addition of a light plaster covering over the bandage insures more accurate immobilization especially in children and heavy persons. Fixation should not be accomplished under stress, but should be comfortable. Particular care should be taken to allow an element of freedom of shoulder movement.

Flaps originating from the contralateral chest surfaces and attached to the hand provide the maximum in patient comfort. In bed they move about with considerable freedom. In addition, they are comfortable upon flexion of the trunk, on ambulation and upon sitting. (Fig. 5.) The arm is held flush with the trunk; this is preferable to the protruding elbow which invites insecurity and changes in

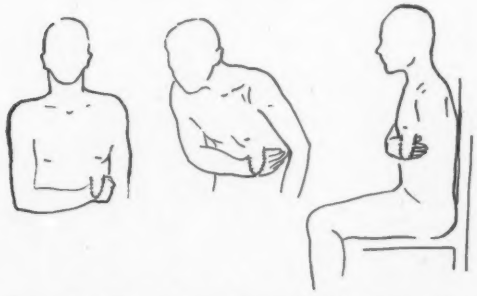

FIG. 5. Mobility and comfort provided by cross chest position of forearm allows patient considerable independence with flap attached.

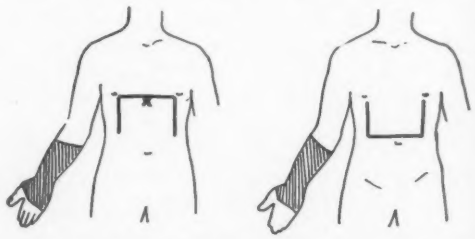

FIG. 6. Flaps based on the mid-anterior surface will provide coverage for large defects. Collateral blood supply at "x" is poor.

the position of the flap. Patients with their arms fixed in the cross chest position can wear street clothes and may be managed on an outpatient basis during the later days of attachment.

Mid-torso flaps: When the recipient defect is large and located on the lower forearm or on the hand, an apron flap based inferiorly just above the umbilicus will provide a great expanse of skin. (Fig. 6.) The width of these flaps may be placed from the fifth interspace to the xyphoid tip. They may be 8 to 10 inches wide and 7 to 8 inches long. The donor defects must be skin grafted. With these flaps it is possible to resurface the lower forearm circumferentially. In some instances it will be necessary to elevate a flap partially and return it to its bed. Delay procedures are more frequently required if the skin is coarse and thick.

Occasionally it is preferable to base these flaps superiorly in the region of the xyphoid. However, application may be technically difficult. The tissue of transfer is that of the upper abdomen and it is somewhat heavier than that above.

From the same side: Flaps based on the lower anterolateral chest on the same side as the involved upper extremity are best suited for coverage about the elbow, forearm and wrist [2,4]. They may be based laterally, superiorly or inferiorly and, if need be, extended to the upper abdomen. Closure of these donor sites is seldom possible, and a skin graft will be required to fill the defect and line the base of the pedicle. These flaps offer the same advantages of excellent tissue and ease of position as described previously. With defects about the upper forearm, there is usually little choice as to other donor sites; therefore, these flaps are not contraindicated by emphysema or sex.

If cross chest pedicles are impractical, lower abdominal flaps are indicated. In 1946 Shaw and Payne [8] described a one-stage tubed abdominal flap based on the epigastric system. (Fig. 7.) These pedicles are well suited for coverage of partial amputations of the hands, for they will permit the insertion of extending bone grafts against which remaining digits may be opposed. Pedicles arising from the lower quadrant of the abdomen for defects of the proximal hand or wrist necessitate placing the hand in the groin. This position limits movement in bed, for flexion, extension or rolling to the side causes tension and torsion on the flap.

FIG. 7. Design of the lower abodminal flap based on the superficial and circumflex iliac system.

Sitting is impossible or at best uncomfortable. With the arm in this position the elbow will extend from the body and add to the instability of the position.

SEPARATION OF FLAPS

Flap grafts are usually separated about the twenty-first day, depending upon their appearance and clinical course. Occasionally a large graft may be delayed, particularly if an extension of the flap is necessary to wrap around the part.

REVIEW OF CLINICAL MATERIAL

Sixty cross chest flap procedures have been done in fifty-one patients. The discrepancy between flaps and patients results from multiple flap procedures in nine patients. In two patients, double flaps were applied and in two others, two separate grafting procedures were performed. Because of circulatory difficulties five flaps were detached, trimmed and reapplied directly. In each instance the second application was successful and gave satisfactory results. The five initial applications were considered failures since it was unwise to leave them in position. The secondary applications were considered as five successful flap grafts. This explains the discrepancy of nine flaps.

Among the sixty procedures, five failed and were abandoned. These flaps, plus the five initial applications listed in Table 1 as failures, constitute the failure rate of ten. Seven other flaps were classed as fair. The remaining forty-three provided excellent or good results. Among the seventeen flaps classed as fair or failed, the principal causes of failure were thrombosis, infection, stretch and carcinoma in two. One of

TABLE I
RESULTS OF SIXTY CROSS CHEST FLAPS

Result	No. of Cases
Excellent	30
Good	13
Fair	7
Failed	10

the latter patients presented a chronic draining burn of many years' duration. Following flap failure squamous cell carcinoma was discovered which subsequently necessitated amputation of the arm. The other patient had carcinoma of the stomach for which he was examined repeatedly. This barrel-chested short man presented an amputation of all the fingers of the right hand. Each time a flap was applied to the hand, vomiting and retching ensued causing failure. Upon recognition of his malignancy, the gastric lesion was resected following which flap grafting was done without incidence. He is alive and well four and a half years later.

The type of injury sustained by the fifty-one patients is shown in Table II. Typically, these injuries resulted in extensive ischemic disturbance.

In half the excellent or good flap transfers, subsequent underlying reconstructive procedures were done successfully. Bone grafting was done in six and in the others, tendon and nerve reconstruction was performed.

These flap grafting procedures have been performed over a period of fourteen years. With experience, the indications for the use of these technics has changed. In reviewing this accumulated material it is estimated that in five of the sixty flap procedures the desired results could have been obtained with migration of local tissues. In six of the remaining fifty-five, a suitable result could have been achieved with free grafts. In three patients, reconstruction of any type now seems contraindicated. Therefore, in forty-six instances flap grafting still appears to be the proper approach.

TABLE II
TYPE OF INJURY

Injury	No. of Patients
Ischemia after injury (infection, damage to Volkmann's canal, frostbite, etc.)	5
Deep extensive burns	5
Electrical burns	5
Extensive avulsion	10
Amputation	5
Gunshot wounds	11
Machinery (corn pickers, presses, shredders, etc.)	10
Total	51

SUMMARY

In an attempt to hasten the transfer of pedicle grafts from the torso to the upper extremity and to provide a greater element of patient comfort, cross chest flap procedures have been used. It has been found that the technic is particularly contraindicated in those persons with barrel chests. Otherwise the method provides excellent tissue for transfer, greatly relieves patient discomfort and allows outpatient care in the later days of flap attachment. While the incidence of ten failures among sixty flaps is unreasonably high, the method offers enough promise to warrant its continued use in carefully screened patients.

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Retrograde Flap—A Coverage Problem

DAVID W. ROBINSON, M.D., FRANK W. MASTERS, M.D. AND CREIGHTON A. HARDIN, M.D.,
Kansas City, Kansas

From the Department of Surgery, University of Kansas Medical Center, Kansas City, Kansas.

EXTENSIVE soft tissue injuries present problems in management. Avulsed surfaces should be covered as soon as the condition of the patient and his wounds will permit the necessary procedures. When the skin, subcutaneous fat and fascia are torn away from underlying structures but are still attached by a pedicle to adjacent vascularized tissue, the decision as to replacement of the detached tissue or removal of the devascularized flap must be made. If the skin of the detached flap is in fair condition, should it be defatted down to the thickness of a split or free full-thickness skin graft, or should split grafts from other donor sites be used to effect coverage? Since the answer to immediate wound care depends upon many factors such as time, terrain, related injuries, type of trauma and the general condition of the patient, a rationale of management requires considered judgment for the security of the patient and his early rehabilitation.

The history of the injury is of prime importance. Time is one essential factor. If several hours have elapsed since the wound was incurred, and infection is already a real threat, the débridement of tissue should be less radical than if the wound were only one to four hours old and not yet inflammatory. If a crushing injury, a burn or any other injury likely to have caused tissue death has already taken place, a greater chance of complications would indicate greater excision of skin and panniculus. If the injury brought considerable dirt down into the tissues, greater cleansing and wider excision of possibly devitalized skin would likely be necessary. If the skin and injuring agent were relatively clean, less cleansing débridement and less sacrifice of tissue might be indicated. Glass cuts, which often occur in auto accidents, are relatively clean, while grinding or crushing injuries from wringers, cornpickers or automobile tires are quite dirty and require much more care and consideration [9].

Examination of the wound and observation after cleansing débridement give the most information for determining whether or not the partially avulsed flaps will survive and can be sutured back. In general, flaps that are rolled back on themselves are devitalized and will die [1]. White skin and subcutaneous tissue that cannot be blanched further on pressure is lost and should be débrided to a good bleeding edge. Wound margins that bleed red blood when cut and exhibit a blanch and return reaction will likely survive. A dusky or bluish color to the skin and a cut surface that oozes dark capillary blood are signs that indicate venous return is impeded. The so-called black gangrene usually occurs when the arterial blood pumped in cannot get out [2], and progressive

FIG. 1. Case 1. Avulsion laceration of forehead of seventeen year old girl cut by windshield glass. Pedicle is narrow and has retrograde blood flow, but is in area of abundant blood supply.

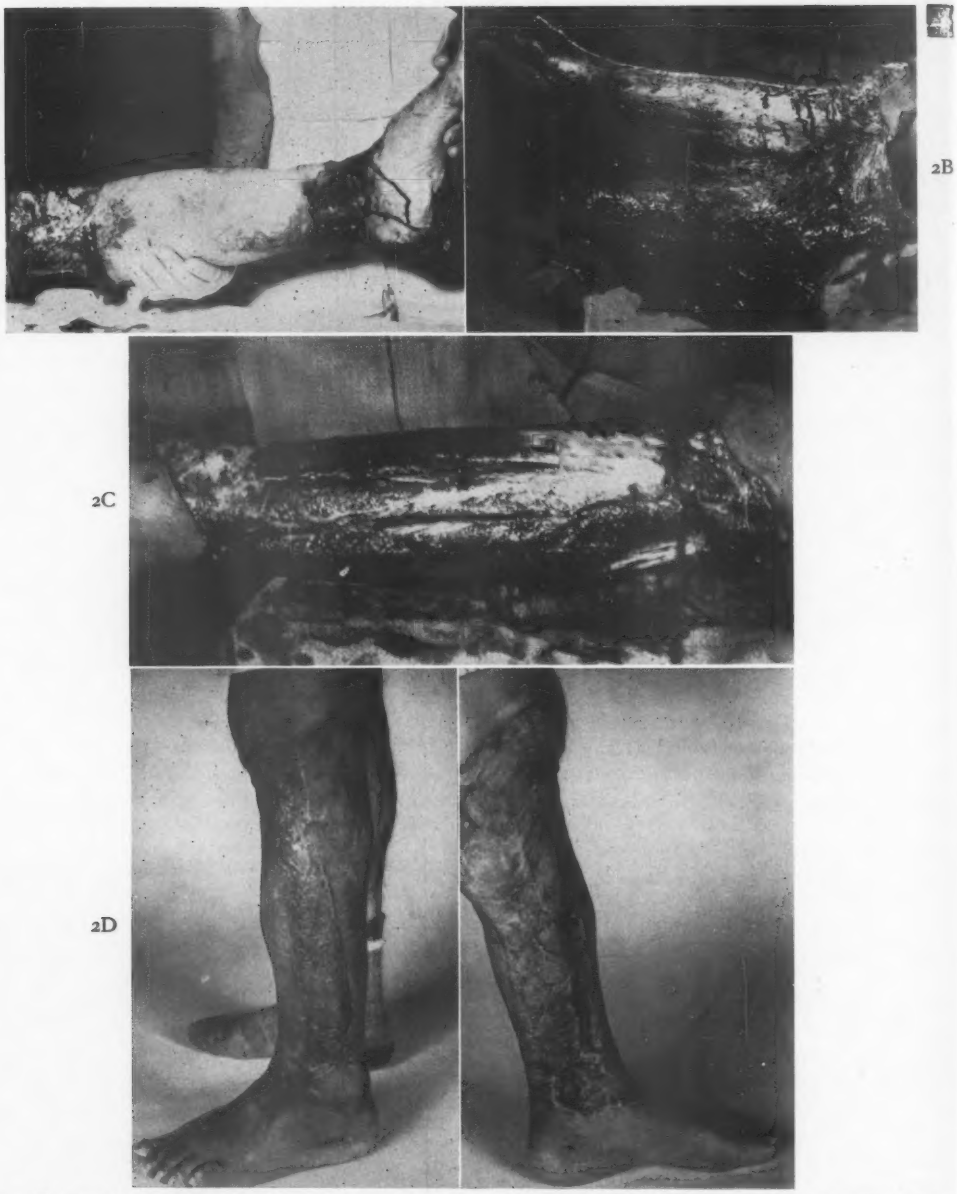

FIG. 2. Case 2. A, extensive avulsion (rubber tire injury) of skin and panniculus of lower leg in seventy year old man. Only attachment was narrow pedicle 3½ inches wide over fibular head and 2½ inches at lateral malleolus. Some muscle crushing with subfascial hematoma. After cleansing débridement, panniculus was loosely sutured back because severe brain damage precluded extensive operative procedure. B, entire skin and subcutaneous fat covering was removed five days later when condition warranted. Note hematomas in muscle compartments. C, granulating wound three weeks later. D, coverage one and a half years after accident. Skin grafts have given good coverage, and patient walks well.

FIG. 3. Case 3. *Top*, power mower injury to hand of six year old boy two hours after accident (as seen in emergency room). Note avulsed flap on dorsum attached only by very narrow stalk. *Bottom*, healing at six weeks. Flap was detached, fat and subcutaneous tissue removed, and skin replaced as free full-thickness skin graft with complete primary coverage.

FIG. 4. Case 4. *Top*, plantar surface nearly completely detached (auto accident) from foot of twenty-one year old boy. Note narrow pedicle in retrograde position. Entire pedicle was removed. *Middle*, primary coverage with skin graft closed wound but skin broke down some months later on slight weight-bearing. *Bottom*, pedicle graft by cross leg flap gave good coverage for weight-bearing.

venous congestion occurs due to thrombosis of veins already damaged by trauma. The width of the pedicle and the anatomic direction of blood flow are the important considerations. Blood supply that enters and leaves through a pedicle that is too narrow or through a retrograde pedicle that is opposite to the normal vascular flow may be inadequate, and progressive gangrene will occur.

The adequacy of blood supply to the parts of the body under consideration is important. For example, the face and scalp have such fine blood supply that a retrograde flow through a distally placed flap (Fig. 1) is of much less importance than such a flow would be in the extremities. Undermining of the panniculus back from the obvious wound edge (Fig. 2A) may be a determining factor of survival. The gloved hand can explore the wound, or an in-

FIG. 5. Case 5. Extensive loss of skin and subcutaneous tissue on lower leg of three year old boy injured by falling under power mower. Only narrow pedicle remains 2 inches in width based just above heel. Flap had been tacked back. Photograph taken as patient was admitted to University of Kansas Medical Center for care five days after injury.

strument may be passed backward to ascertain such detachment. What appears to be adequate circulation may be quite insufficient when the inevitable edema occurs a few hours later, or when an uncontrolled capillary ooze in muscle or fat builds up internal tissue pressure by hematoma in a closed space. This pressure may be sufficient to shut off arterial flow in an arteriole already in spasm from trauma, or impede venous return. Fat necrosis from distant trauma or devascularization causes further edema which may compound the process [3], and the presence of dead tissue promotes infection which also causes further edema with subsequent reduction in blood supply.

Treatment, therefore, should be directed toward the prevention of such processes and toward effecting wound closure as quickly as feasible. Thorough cleansing débridement with careful removal of dead, dying or potentially dying tissues should be done as early as the general condition of the patient permits. Hematomas are evacuated. Incisions of fascia over swollen muscle may help the blood supply. If the flap on a narrow stalk does not meet the criteria of the living, it should be detached back to good arterial bleeding. The skin, if not too damaged, can be used for coverage by removal of all the fat into the dermis, returning the skin as a free graft for wound dressing [4–6]. (Fig. 3A.) If the skin is doubtfully viable, it should be discarded [7], and free split grafts from other donor sites used for coverage [8]. Not infrequently, when tendons, nerves or bones are left exposed, pedicled graft coverage from adjacent tissue or from a distant source must be used to protect these structures and facilitate further reconstructive operative procedures. If persisting oozing is present or if the patient's general condition is precarious, a simple fine-meshed gauze dressing should be applied next to the wound, followed by a bulky resilient pressure dressing [1]. When extremities are involved, elevation is valuable. Within two to four days, a skin graft can be applied with less danger of loss from hematoma or further necrosis of tissue from the original injury. Much time will be saved and a better ultimate result will be obtained if the proper judgment is exercised early in the care of these wounds [3]. Antibiotics and tetanus prophylaxis are indicated.

Illustrative cases are shown in Figures 1 through 5.

CONCLUSIONS

Avulsed flaps partly attached but devitalized either directly from the trauma or by interference with the circulation should be discarded, and the wound (after proper débridement) closed by free grafts or pedicle. Closure of such wounds by suture of these doubtful flaps back into their beds delays wound healing by compounding the wound necrosis from edema, closed space hematomas and infection. Pressure dressings and elevation help prevent a venous type of gangrene.

SUMMARY

1. The problem of the partially detached flap at a wound margin is presented and discussed.

2. The history of the wounding and the appearance of the wound affect closure and care.

3. Devascularized flaps should be detached and the skin, if not damaged, may be used for immediate wound coverage after radical defatting, or free split grafts from other donor sites may be employed.

4. Pedicle tissue is used primarily to protect important structures or to facilitate future reconstruction.

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DISCUSSION OF PAPERS BY DRS. POWERS AND PROTHERO; WHITE; AND ROBINSON, MASTERS AND HARDIN

W. T. MEDL (New York, N. Y.): Avulsed pedicle skin must not be handled as man-made pedicle flaps. I think all of us should make an attempt to instruct the young surgeon properly that these flaps made roughly differ greatly from flaps cut carefully and deliberately by a surgeon. These flaps must be excised and the skin examined. Unless the skin has been very badly damaged, it is usual to use it as a full-thickness graft or, in some instances, as a split graft. I believe these points were extremely well brought out, and in Dr. White's presentation of his beautifully made pedicle flaps, we found that even in his hands occasionally part or all of the flap was lost. If he can lose flaps in spite of this care, obviously roughly made flaps are going to be lost much more easily.

H. H. STRYKER (Kalamazoo, Mich.): Recently a patient caught his arm in a rewinder paper machine and separated the skin from about 3 inches above the elbow down to the wrist. I recalled the paper in Chicago on the retrograde flap, so I cut it off about mid-forearm, and defatted and reapplied it. Although there were no broken bones, all the musculature of the forearm was pretty well musculated, and most of the muscles were detached at their origin. We had to remove most of the macerated musculature of the forearm. About half of the graft survived. It died over the bare ulna. The ulna nerve had been severed and will be repaired later, and a flap graft from the abdomen placed over the denuded ulna.

If I were to handle it again I do not know what I could have done to improve it. I am convinced we would have lost most of the flap if we tried to pull it back up over the forearm originally. This patient will have sensation in his hand but the muscles of his forearm are quite dilapidated. Just how much function he will have is not known.

Treatment of Fire Victims: Lady of the Angel School Disaster

JAMES J. CALLAHAN, M.D. AND JAMES E. SEGRAVES, M.D., *Chicago, Illinois*

From St. Anne's Hospital, Chicago, Illinois.

THE fire in our Lady of the Angel School on December 1, 1958, injured a large group of human beings. Most of the victims were children. Their serious burns were complicated by a multiplicity of other injuries, including a wide variety of fractures. Casualties were brought to four different hospitals. The staff of St. Anne's Hospital had been prepared for a hypothetical emergency and was thus enabled to function as a team in caring for the sudden large influx of seriously injured patients. Therefore, the statistical record of successful treatment was gratifying.

The plan of management in the event of disaster to a large group was simple. It revolved around a central figure, the Chief of the Disaster Team, who had written the procedure to be followed by all personnel involved in such an eventuality. He had rehearsed the major steps with the team at frequent intervals. The plan presupposed the type of cases requiring treatment, which team was to be used, and the areas in which each team would function. The plans for treatment included only the first twenty-four hours after the disaster. The treatment for the succeeding twenty-four hours was outlined in daily conferences with the members of the team in the light of the experiences of the preceding twenty-four hours.

STATISTICS

Seventy-four casualty victims were admitted to the hospital. Six others were dead on arrival; four additional ones died almost immediately after their admission to the emergency room. Twenty-four patients were ambulatory and could be dismissed after treatment. These had suffered minor first degree burns on exposed parts of the body, contusions and abrasions of the soft tissue, smoke inhalation and hysteria. One patient had a fractured fibula, for which a cast was applied, and the patient was discharged to his home.

Forty-six patients remained in the hospital. They had first degree burns over varying percentages of the body. This group of patients with first degree burns was not included in the estimates of total skin area burned. Six children had second and third degree burns covering 60 per cent of the body. Of these six, one had burns over 90 per cent of the body, and another was burned over 80 per cent of the body. Thirteen were burned in varying degrees up to 40 per cent of total skin area.

COMPLICATING INJURIES

The burns were complicated by other injuries, including thirty-six fractures which ranged in seriousness from a fractured neck of the femur to a fracture of the transverse process of the first lumbar vertebra. Two patients had dislocations of the cervical spines, one had a crushed chest with probable multiple fractures of the ribs, one had tension pneumothorax, and two had basal skull fractures. In addition, there were many cases of multiple contusions and abrasions caused by gravel and dirt. This had been ground into the skin and soft tissues, particularly around the hands and knees, when the victims fell or jumped from the second story windows to the gravel paths below.

LOCAL TREATMENT OF BURNS

The burns were treated by the exposure method advocated by the Brooke General Hospital Burn Research Unit. Eighteen patients were placed on Stryker frames because of circumferential burns of the trunk which made handling difficult. The local wounds

were débrided of gross contamination and protected by sterile sheets. The patients were either put to bed or placed on a Stryker frame as noted. The patients were protected from drafts by sheets over the frames and later by electric blankets. The electric blankets proved better not only in protecting the patients from colds and drafts but also in promoting faster development of eschar.

Eschars began to form within the first twenty-four hours and were watched carefully; any defect in the eschar was immediately cultured and tested for sensitivity to various antibiotics. At the end of the second week when the eschars were well formed and the patient's general condition was satisfactory, the eschar was débrided, small sections at a time. Split-thickness skin grafts were applied. In most instances autogenous grafts were used, but lyophilized homogenous grafts provided by the Bureau of Medicine and Surgery of the U. S. Navy Department were used as were homogenous grafts from the parents of the children. Hands were immobilized in a position of function. Elbows, knees and other points of contact were wrapped in pressure dressings, in many cases, in order to permit easier handling.

USE OF FLUIDS

A large supply of aged plasma was on hand, so that it was not necessary to make use of plasma expanders. Whole blood and electrolytes including distilled water, from 5 per cent to 10 per cent saline solution, lactated Ringer's solution and Hartmann's solution were all employed.

For six patients, we also used blood obtained from previously burned patients. This was given in 10 cc. units of whole blood as well as, in incompatible persons, 500 cc. units of plasma. A total of 3,500 cc. of such blood was used. Difficulties in matching and the delay in obtaining the blood made its usefulness doubtful.

A total of 72,200 cc. of whole blood was given in addition to 45,395 cc. of aged plasma. This, combined with electrolytes totaling 371,694 cc., made a grand total of 489,289 cc. of colloidal fluids and electrolytes administered during the course of treatment of this series of patients.

CHEMOTHERAPY

A broad range of antibiotics were administered. Combiotic® was initially given except in two patients with known sensitivity to penicillin. These patients received Albamycin® as an initial antibiotic. During the next four months a whole range of antibiotics was tried; the most useful proved to be Bacitracin.® A spray of 1 per cent Bacitracin and Neomycin® was used with excellent local results.

Tetanus antitoxin was given to all patients on admission. Lyophilized urea was given to the most critically burned children, as was Diuril.® Therefore, edema was not a problem.

Conservative treatment in the form of vitamin therapy, including large amounts of vitamin C, was on demand. Narcotics were used sparingly, and few were required. Sedatives for sleeping were rarely needed. Protein mobilizers were of little value except for a preparation with the trade name of albedecone, a preparation of hesperidin methyl chalcone and minerals, which we thought was of value.

TREATMENT OF COMPLICATIONS

Patients with fractures were treated by immobilization and casting within two hours after admission to the hospital. Skeletal traction was applied in the patient with a fracture of the neck of the femur and a supracondylar fracture of the humerus. Crutchfield tongs were applied for traction in one patient with a dislocated cervical spine. Two tracheotomies were required, and Bennet respirators were necessary in two patients to maintain pulmonary rhythm and bronchial toilet. Water-sealed drainage was instituted in one patient for tension pneumothorax. Burr holes were made in one patient in whom a brain abscess was suspected. Open reduction with internal fixation of the fracture of the neck of the femur was performed four months after the injury when the skin had healed and was clean enough to permit surgical intervention.

All patients were catheterized immediately after admission to hospital beds. Foley catheters were left in place to measure the output in those patients burned over more than 15 per cent of the body.

LABORATORY PROCEDURES

Complete microhematocrit readings and urinalyses were made twice daily. All patients were typed and cross matched on the first day as soon after admission to the hospital as was possible. The hematocrit readings were con-

tinued twice daily until the patient's condition was stabilized, then once daily, and finally, twice weekly. Blood protein, blood sodium and chloride determinations were made daily when indicated. These were continued until the patient's condition had stabilized and the patient was apparently out of danger. Blood cultures and cultures of the drainage from the wounds were done as were sensitivity tests, as indicated and ordered. Whenever possible the blood specimens were from capillary blood. A capillary pipet was employed. Micro methods of determination were applied whenever possible.

RESULTS

Four patients died. One of these died of complicating injuries, not of the burns which in this particular case were minor. One, who was burned over 90 per cent of the body during the original injury, died of shock after débridement for skin grafting. One died of septicemia from multiple abscesses, including meningitis; and one died of hepatitis and septicemia which developed eight months after second and third degree burns of 80 per cent of the body.

All of the fractures in this series except one have healed. The exception is a fractured neck of the femur, which at the time of this writing shows roentgenologic evidence of formation of callus and apparent satisfactory circulation in the head. Good functional results in all patients are recorded at eight months' review.

Skin grafting has proceeded satisfactorily in twelve patients, but one died after eight months of treatment. Three patients are still in the process of treatment with grafts. Further plastic revision of grafts will be needed in at least eight additional patients in this series because of contractures and keloids.

CONCLUSIONS

1. A medical staff properly prepared and willing to work as a team is able to meet and overcome the obstacles in treating a sudden influx of severely burned and injured patients.

2. The exposure method is apparently the best treatment of burns in a mass casualty situation.

3. Septicemia is still a grave threat to a severely burned patient. Active administration of fluids to replace loss and combat shock is of utmost importance at the outset. Relaxation of this program of replacement cannot be permitted if renal shutdown and shock are to be prevented.

Blood from convalescent burned patients supposedly contains antibodies formed in response to burns sustained by donors. Its use is intriguing and warrants continued study. However, the patients in our series received too little such convalescent blood too late to estimate its value. Evaluation of benefits received from this were also hampered by the lack of objective methods of measuring the patient's response.

Rotary Power Mower Injuries

WILLIAM A. JOHNS, M.D., THOMAS R. BUTTERWORTH, M.D. AND JOHN H. GREIG, M.D.,
Richmond, Virginia

From Johnston-Willis Hospital, Richmond, Virginia.

IT is a sad fact that as man strives to make life more pleasant by developing devices to ease the burdensome chores of everyday living, he invariably succeeds in making life more hazardous. This fact is exemplified in the case of rotary mowers.

The potential for destruction and maiming within these machines is well known, and it has been the subject of numerous articles in both the medical and lay press [*2–5*]. Since 1957 there have been determined efforts by various responsible authorities in the Richmond, Virginia area to educate the public concerning the safe use of the mower and the dangers associated with it. This has included articles in the local newspapers, a pamphlet prepared by the Richmond Area Safety Council and given to potential purchasers of power mowers, and specific safety drives by large manufacturing firms concerned with the increased loss of man-hours due to accidents with the mowers. The manufacturers of the mowers added new and improved safety features to many of the models.

Seemingly, there should have been a decrease in the number of such injuries admitted to the emergency room of our hospital, since a series of fifty cases was reported by Butterworth in 1957 [*1*]. Only a small proportion of the total cases of trauma in the Richmond area are seen in the emergency room, but we have been impressed by the numerous rotary mower injuries which continue to require treatment. We decided to review and compare the numbers and types of such injuries in the years preceding and following the introduction of the previously mentioned safety campaigns.

The type of injury sustained falls into one of three categories. The first group includes injuries to the lower extremities. The patient usually gives a history of slipping on wet grass or on a slope into the machine, although one such accident occurred while a salesman was demonstrating a riding type mower on a level non-slip floor in a department store.

CASE I. One of our patients, a fifty-six year old man, slipped and pulled the mower onto his left foot. The blade amputated the little toe and partially severed the fourth toe. (Fig. 1.)

CASE II. A twelve year old boy slipped and pulled the mower onto his right foot. The machine amputated the great and second toe and part of the medial side of his foot. (Fig. 2.)

FIG. 1. Case I.

FIG. 2. Case II. (FROM: BUTTERWORTH, T. R. [1].)

Injuries to the upper extremities compose the second group. The history usually reveals carelessness on the part of the user, who attempts to clean the blades or adjust the machine with the motor running.

CASE III. While cleaning debris from the machine with the blade rotating, a twenty-nine year old man avulsed the tip of his left ring finger and lacerated and fractured the middle finger. (Fig. 3.)

CASE IV. A thirty-three year old man attempted to remove weeds from the blade without stopping the motor and amputated the tips of his left index and middle fingers. (Fig. 4.)

The third group includes accidents which occur when the blade strikes a solid object resulting in a fragment of the blade or the object being flung out of the machine at high velocity. The victim is usually a bystander and often a child.

CASE V. In this case, a sixteen year old bystander was struck on the anterior surface of the right leg by a piece of wire. The wound through which the object entered was approximately the size of a dime. The wire hit and embedded in the tibia.

CASE VI. A twenty-nine year old man was struck while he was operating his mower. The object struck the anterior surface of the right leg. It hit the fibula and bent, but it did not penetrate the bone. Again, the foreign body was a piece of wire.

CASE VII. A fifty-six year old woman was struck by a piece of wire which penetrated a canvas shoe and embedded lateral to the proximal phalanx of the right little toe. (Fig. 5.)

Table 1 shows the total number of injuries and the figures for each of the three groups previously described during the periods of 1954 through 1956 and 1957 through July 1959. If

TABLE 1

Year	No. of Injuries by Groups			Total
	1	2	3	
1954–1956	22	22	6	50
1957–1959	20	18	5	43

FIG. 3. Case III.

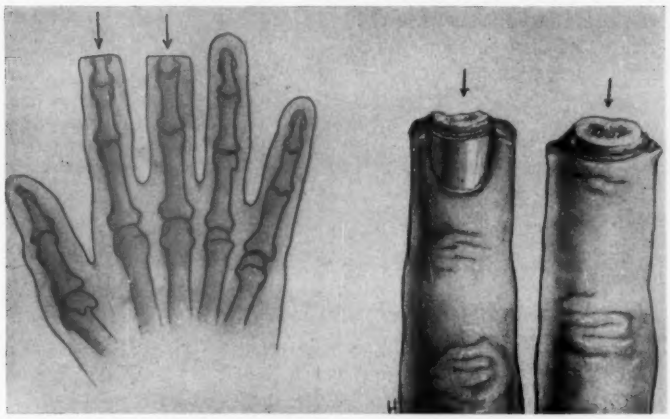

FIG. 4. Case IV. (FROM: BUTTERWORTH, T. R. [1].)

FIG. 5. Case VII.

the preventive measures previously outlined had been effective, it would be reasonable to expect a drop both in the total and in the group of injuries attributable to carelessness, but no significant decrease took place. Therefore, we believe that warning the public of the dangers is not the answer, that safety campaigns are doomed from the outset because of the optimism of the people who "know it can never happen to them." Any future improvement must come from the addition of more safety features to the mowers.

Favorable progress has been made in this direction by several manufacturers who have on their products such features as improved shields and footguards, controls mounted on the handles and prominent warning notices on the body of the mower. Unfortunately, there are still machines on the market which incorporate few, if any, of these aids to safety. Perhaps a mandatory schedule of safety standards should be applied before a rotary mower is offered for public sale. It is our hope in presenting this paper that efforts will be continued to reduce the number of accidents caused by these appliances.

SUMMARY

A series of injuries caused by power mowers before and after the introduction of public warning campaigns are compared. No lessening of the incidents or alteration in the type of

injuries encountered could be found within the two groups. It is suggested that further efforts should be directed to improving the safety features on the mowers.

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Fat Embolism: The Significance of an Elevated Serum Lipase after Trauma to Bone

LEONARD F. PELTIER, M.D., PHD., FEDERICO ADLER, M.D. AND SING-PING LAI, B.S., M.S.,
Kansas City, Kansas

From the James B. Weaver Laboratory for Orthopedic Surgery, University of Kansas Medical Center, Kansas City, Kansas. This study was supported by Grant No. 3592 from the United States Public Health Service.

WE are slowly reaching a better understanding of the pathogenesis of fat embolism [7]. The initial stage of mechanical obstruction of the pulmonary vascular bed is seldom recognized clinically. The secondary stage of chemical disruption of the endothelium of the pulmonary capillaries due to the action of fatty acids freed by hydrolysis of the neutral fat emboli is the stage at which the classic signs of dyspnea, disorientation and petechial hemorrhages permit the diagnosis of fat embolism to be made. The latent period is that period after the arrival of neutral fat emboli in the lung during which the hydrolysis of the neutral fat occurs with the freeing of toxic fatty acids. This hydrolysis results from enzymatic activity, and for this reason the study of the serum lipase in patients in whom fat embolism might be anticipated becomes of special interest.

Studies of the serum lipase and serum tributyrinase levels in patients following trauma to bone have been reported by a number of European authors [5,6,13–17]. They are in general agreement that: (1) the serum lipase and/or tributyrinase rises in a substantial number of patients following trauma to bone; (2) the increase in enzymatic activity is directly proportional to the degree of trauma to bone; and (3) with few exceptions, patients in whom a diagnosis of fat embolism can be made, either clinically or at autopsy, have an elevation of the serum lipase and/or serum tributyrinase.

A preliminary survey of seventy-five patients with a wide variation in the degree of trauma to bone was made [10]. Significant elevations of the serum lipase level occurred in sixteen. The highest incidence of significant elevations in the serum lipase occurred in those patients with multiple fractures and extracapsular fractures of the hip. With this information at hand, an additional group of thirty-eight patients was studied. These patients, selected to insure a higher incidence of significant serum lipase changes, had either multiple fractures or extracapsular fractures of the hip. The substance of this report consists of our experience with the entire group.

METHODS

The serum lipase levels were determined by the method of Cherry and Crandall [1] as modified by Comfort and Osterberg [3]. The method consists essentially of the incubation of 1.0 ml. of serum with a buffered olive oil emulsion at 37°C. for twenty-four hours. The free fatty acids released by hydrolysis are then titrated to an end point with 0.05N NaOH. The results are reported in terms of milliliters of 0.05N NaOH. In our laboratory, eighty-one normal samples were examined as controls; 95 per cent of these fell into a range of 0.0 to 0.85 ml. of 0.5N NaOH. In this study we have considered any serum lipase level in excess of 1.0 ml. to be significantly elevated.

Blood was drawn using disposable plastic syringes, transferred to centrifuge tubes, allowed to clot, and then centrifuged. If the determination was not begun immediately, the serum was frozen. Blood samples from emergency cases were drawn immediately after admission. Blood samples from elective surgical patients were drawn in the operating room at the time anesthesia was begun. Subsequent samples were drawn in the early morning, usually before breakfast had been served.

TABLE I
AGE DISTRIBUTION OF 113 PATIENTS

Age (yr.)	No. of Patients
10–19	11
20–29	6
30–39	15
40–49	13
50–59	16
60–69	12
70–79	20
80–89	16
90–99	4

Blood samples were obtained on the day of admission or operation, and on at least four successive days. When the serum lipase was significantly elevated, additional samples were drawn.

RESULTS

Of the 113 patients, sixty-seven were men, and forty-six women. Their age distribution can be seen in Table I. Nineteen patients had multiple fractures, seventy-two had single fractures, and forty-four underwent elective orthopedic operations. Thirty-seven of the patients showed significant elevations of the serum lipase. (Table II.) Eight of the patients died, and in six autopsy examination was permitted. (Table III.) In only two of the patients (Cases 7 and 8) was the serum lipase significantly elevated. There were nine patients in whom the serum lipase was markedly elevated, i.e., above 2.0 ml. None of these patients died. There was only one patient in whom a clinical diagnosis of fat embolism was made on the basis of the classic findings of dyspnea, disorientation and multiple petechial hemorrhages. This patient, who had a fracture of the shaft of the femur, survived after a stormy convalescence. The course of the serum lipase levels in this patient can be seen in Figure 1.

The changes in the serum lipase levels were remarkably consistent in many of the patients. The serum lipase did not begin to rise until three to five days after injury, reaching its maximum after five to eight days. Figure 2 is a composite curve constructed by averaging the serum lipase levels from eighteen patients with extracapsular fractures of the hip. The value of this construction is to demonstrate the

TABLE II
INCIDENCE OF SIGNIFICANT ELEVATIONS OF SERUM LIPASE IN PATIENTS AFTER TRAUMA TO BONE

Diagnosis	No. of Patients	No. of Patients with Elevation
Multiple fractures:		
Hip (extracapsular) tibias (shafts)	1	..
Acetabulum, clavicle	1	..
Acetabulum, dislocation of hip	3	2
Femur, tibia	3	2
Femurs (open)	1	..
Tibias (open)	1	..
Hip (extracapsular), humerus, mandible	1	1
Tibia, humerus, L5, ribs	1	1
Tibia (open), pelvis, ribs	1	1
Fracture-dislocation humerus, pelvis	1	..
Humerus, facial fractures	1	1
Forearm, patella, mandible	1	..
Forearm, ribs	1	1
Ribs (8)	1	1
Femur, mandible	1	1
	19	11
Single fractures:		
Rib	1	..
Vertebral body	3	..
Pelvis	1	..
Colles'	1	..
Hip, intracapsular	8	..
Hip, extracapsular	35	19
Femur, shaft	10	4
Patella	1	..
Tibia and fibula	5	..
Ankle	3	1
Os calcis	4	1
	72	25
Elective orthopedic operations:		
Osteotomy, femur	7	1
Insertion prosthesis, hip	1	..
Insertion pins, femoral neck	1	..
Amputation through femur	1	..
Arthrotomy, knee	3	..
Sequestrectomy	2	..
Subastrangular fusion	1	..
Débridement, elbow	1	..
Débridement, ankle	2	..
Wrist fusion, bone graft	1	..
Excision of soft tissue sarcoma	1	..
Non-union, forearm, bone graft	1	..
	22	1
Total	113	37

TABLE III
CAUSES OF DEATH OF PATIENTS IN STUDY GROUP

Case No.	Age (yr.) and Sex	Primary Diagnosis	Survival after Fracture (days)	Maximum Lipase Level (ml.)	Autopsy	Cause of Death
1	79,M	Intracapsular fracture of hip	15	0.68	No	Pulmonary embolus
2	87,M	Extracapsular fracture of hip	6	0.84	Yes	Fat embolism
3	40,F	Intracapsular fracture of hip	2	0.22	Yes	Fat embolism
4	91,F	Extracapsular fracture of hip	11	0.63	Yes	Fat embolism
5	77,F	Extracapsular fracture of hip	23	0.53	Yes	Wound infection, bleeding peptic ulcer in stomach
6	86,F	Extracapsular fracture of hip	13	0.96	Yes	Pulmonary embolus (occasional fat emboli)
7	93,F	Extracapsular fracture of hip	6	1.04	Yes	Fat embolism
8	79,M	Extracapsular fracture of hip, diabetes	14	1.61	No	Gastric dilatation, myocardial infarction

typical configuration of the curve formed by the daily serum lipase levels.

Only two of the eight patients dying after injury had elevations of the serum lipase. Of the six patients in whom postmortem examinations were made, four died as a direct result of fat embolism, but in only one was the serum lipase elevated.

COMMENTS

Our experience gives general support to the findings of others that: (1) the serum lipase becomes elevated in a substantial number of patients after trauma to bone; and (2) the increase in enzymatic activity is directly proportional to the degree of trauma to bone.

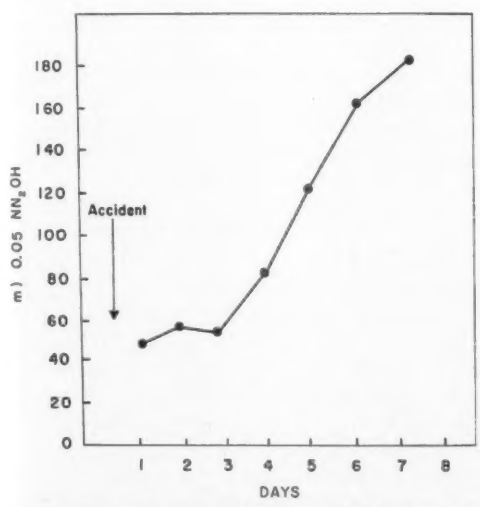

FIG. 1. Changes in the serum lipase level in a patient with clinically severe fat embolism following a fracture of the shaft of the femur.

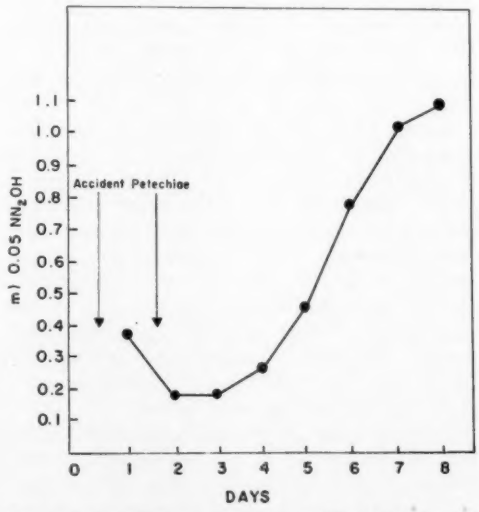

FIG. 2. A composite curve constructed by averaging the serum lipase levels of eighteen patients with extracapsular fractures of the hip.

The source of the increased serum lipase is the lung. The secretion of lipase as a non-respiratory function of the lung parenchyma was first recognized many years ago by Rona [12], who was able to differentiate between the lipase secreted by the liver, pancreas and lung by means of various inhibitors. Gomori [4] has demonstrated lipase secretion in the lung alveoli by means of histochemical methods. We have found histochemical evidence of increased lipase activity in the lungs of patients dying of fat embolism [8]. Previous studies of the serum tributyrinase levels in dogs following the intravenous injection of neutral fat in the emulsified and non-emulsified state, as well as non-fatty materials producing diffuse pulmonary embolism, demonstrated that an increase in the serum tributyrinase activity took place only in those animals with diffuse pulmonary embolism of neutral fat [11]. A group of thirty-one patients undergoing abdominal operations for various conditions were examined for changes in the serum lipase activity in a manner similar to the group of patients with fractures. In this group, the serum lipase activity became elevated only in those patients with biliary or pancreatic disease or in whom extensive manipulation of the pancreas was carried out at the time of operation. Characteristically, the serum lipase activity in these patients became markedly elevated immediately and the return to normal levels was well underway by the third postoperative day, the time at which the serum lipase was just beginning to become increased in the patients with injuries to bone [9].

Cobb et al. [2] have measured the length of time dogs require to rid their lungs of emboli of neutral fat tagged with I^{131}, by measuring the uptake of I^{131} over the thyroid gland. The maximum uptake occurred about six days after the intravenous injection of the tagged fat. A comparison of their curve of I^{131} uptake by the thyroid and the serum lipase curves in our patients reveals an excellent time relationship between enzymatic activity and I^{131} uptake, an end point in the removal of neutral fat emboli from the lung.

The elevation of the serum lipase following trauma to bone is due to an increase in the lipase secretion of the lung parenchyma as a response to the presence of multiple emboli of neutral fat. Unfortunately, significant elevations of the serum lipase do not occur until two to three days after injury, and for this reason the serum lipase level is of no real value in the early diagnosis of fat embolism or in the early selection of patients in whom clinical fat embolism is apt to appear. Later on, i. e., three to six days after injury to bone, the serum lipase level may provide information of real value.

In the patient with multiple injuries, including an injury to the head, an elevated serum lipase may, by suggesting the possibility of fat embolism, help to evaluate the over-all clinical picture and place the cerebral signs in a different prospective. Perhaps more important, a markedly elevated serum lipase in a patient with severe injuries to bone carries a good prognostic significance. It should be noted that in none of our patients with serum lipase levels in excess of 2.0 ml. did death occur. Among the four patients dying of fat embolism, the serum lipase was elevated above 1.0 ml. only once, and in this case to only 1.04 ml. These observations may be explained by the fact that when damage to the capillary bed of the lung is severe and hemorrhagic infarction occurs, circulation through these areas is arrested and lipase secreted locally cannot reach the general circulation. On the other hand, when circulation is preserved through the involved area of lung parenchyma, the lipase secreted reaches the general circulation, giving a markedly elevated serum lipase. The serum lipase level in a general way reflects the degree of disorganization of the pulmonary capillary bed. Obviously, if the patient succumbs to the mechanical effects of the embolic fat and dies quickly within twelve to forty-eight hours, the serum lipase will not be elevated.

CONCLUSIONS

The serum lipase activity increases in a substantial number of patients following trauma to bone. This increase occurs three to five days after injury, reaching its maximum between five and eight days. A markedly elevated serum lipase level in a patient with severe injuries to bone accompanied by fat embolism implies a good prognosis for recovery.

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DISCUSSION

M. M. Musselman (Omaha, Neb.): Dr. Peltier has been carrying out critical studies of fat embolism for several years. We all agree he has reported interesting findings in his paper but I know many of us would disagree on the importance of fat embolism, that is, as a complication or cause of death in our patients.

Some doctors have told me that they have seen few, if any, patients with fat embolism. Furthermore, they say patients with fat embolism usually die. On the contrary, I believe fat embolism occurs frequently in injured patients, but most of them live.

I believe fat embolism occurs in about one-third of patients with severe injuries to soft tissue, in about half the patients with severe burns, and about two-thirds of patients with fractures of long bones. About 10 per cent of patients having fat embolism will die as a result of it. Therefore, I think Dr. Peltier's studies are of great clinical importance.

I cannot tell you how to save the lives of those people now dying of fat embolism. I do not know enough about the pathogenesis of fat embolism or of the effect of fat embolism on the body. Dr. Peltier, by his studies, has confirmed the frequency of fat embolism. He has given us another means of confirming the diagnosis. Furthermore, he has given us a better understanding of the effect of fat embolism on the body and of the response of the body to fat embolism. Such studies will lead us eventually to a rational and effective treatment for fat embolism.

C. P. Artz (Jackson, Miss.): I enjoyed Dr. Peltier's paper and would like to cite our Korean experience. When the team went to Korea it was believed that fat embolism would be the cause of death in many of the severely wounded patients with fractures. Two pathologists studied the problem and found that fat embolism was the cause of death in very few patients. It was found most often as the cause of death in the patients who came to autopsy after beatings in the Korean prisons. The Korean prisoners had a method of killing their unwanted confreres by wrapping them in blankets and beating them with clubs. The cause of death in persons so treated was fat emboli in the brain.

We see many patients with fat emboli in the lungs. I do not think this is significant as a cause of death. I do not believe I have ever seen a death due to fat emboli in a patient with burns, and we have looked for emboli many times.

L. F. Peltier (closing): I appreciate the comments of Drs. Musselman and Artz. The report of the pathologists from Korea was interesting to me because it was at complete variance with the experience of the Committee for the Study of Severely Wounded in World War II and its British analogue, along with other reports from the Armed Services.

The problem we are trying to solve is this: If fat

embolism exists, there must be some method of treatment. Intravenous alcohol and heparin have been used, based on clinical impressions. We hope to get some background data in terms of blood lipase activity, in objective measurement. We are then going to treat certain patients with some of these suggested remedies to see whether we can get any objective changes in the laboratory tests to support the thesis that you can change the course of this pathologic process by treatment. I think this is the only way to obtain a basis for any claim of the effectiveness of treatment.

Experience with Intrathoracic Injury Following Automobile Accidents

WILLIAM G. PACE, M.D., EDWARD PASSARO, JR., M.D. AND KARL P. KLASSEN, M.D.,
Columbus, Ohio

From the Department of Surgery, The Ohio State University Health Center, Columbus, Ohio.

BECAUSE the steering wheel is a dangerous weapon automobile manufacturers have taken steps to cushion it and make it smaller, but it still remains a potential cause of serious trauma. This study presents the management and prognosis of those persons surviving the initial intrathoracic trauma received during automobile accidents.

The records of over 400 patients admitted to the University Hospital following automobile accidents over the past ten years were reviewed. All patients admitted primarily because of injury to the chest were included in this study. Patients with neurosurgical, orthopedic or intra-abdominal injuries were excluded as were those having simple rib fractures without significant intrathoracic trauma [1].

Of the seventy-six patients admitted primarily for serious intrathoracic injury, the over-all mortality rate was 20 per cent. Only thirteen patients sustained isolated intrathoracic injury. All these patients had hemothorax, pneumothorax or hemopneumothorax, were treated with closed thoracotomy, and discharged within two weeks. On the other hand, all the patients who died presented with injuries to the chest and multiple associated injuries.

The most commonly seen intrathoracic injury was hemopneumothorax. The average age of this group of patients was thirty-seven years. In fifteen of the sixteen patients in this group, the diagnosis was established by physical and roentgenographic examination. The intrathoracic injury in the remaining patient was overlooked initially because of injury to the abdomen. Major complications developed in one-third of this group during hospitalization. The average length of hospitalization of these patients (two and a half weeks) was the longest of any of the major groups of patients treated. Repeated aspiration of reaccumulating fluid and air, although not uncommon at one or two weeks after the initial injury, prolonged hospitalization for these patients. Prior to 1955 the treatment of choice was repeated needle aspiration of fluid and air. Since that time, closed tube thoracotomy has been followed with continuous suction for forty-eight hours. There have been no instances of empyema following either of these methods and no subsequent pulmonary incapacity. Two-thirds of these patients had associated injuries such as minor fractures which did not influence their hospitalization.

Pneumothorax occurred in fifteen patients: on the right side in eleven, on the left side in four and bilaterally in one. The diagnosis was established and treatment instituted in the emergency room. The average length of hospitalization of this group was 1.9 weeks and the average age, twenty-seven years. Only two patients in this group had major complications. Both were secondary to concomitant neurologic injuries. Prior to 1955, such patients were treated with repeated needle aspiration of the pneumothorax or were kept under observation. In recent years the hospital course and morbidity of patients with this injury have been decreased by the use of closed tube thoracotomy. Antibiotics are not routinely used, and empyema has not been observed during the course of follow-up examinations. Not one of the patients in this group required repeated aspirations.

Thirteen patients were treated for hemothorax. Although the average age of this group

FIG. 1. Primary suture of involved ruptured bronchus.

of patients was forty-nine years, the duration of hospitalization was only 1.9 weeks. Minor complications developed in four of these patients but in none was the hospital course prolonged. Pulmonary edema developed in one patient who had received blood transfusions, and phlebotomy was performed. A second patient with a history of emotional disturbance had symptoms of his illness during hospitalization. One patient showed signs of shock from blood loss on the day of admission and a fourth patient required reaspiration for a second hemothorax. The diagnosis in these cases was established by physical and roentgenographic examination. The highest number of erroneous diagnoses were made in this group of patients, five of thirteen diagnoses being missed initially.

The treatment of these patients varied. Six were treated with closed thoracotomy, three with open thoracotomy, and the remaining patients with needle aspiration only. In recent years the tendency to use open thoracotomy when there is any suspicion of progression or inadequate evacuation has increased. There were no deaths in this group of patients.

Four patients were admitted with crushed chests but had no other significant intrathoracic injury. The average age of the patients in this group was fifty-eight years, and the length of hospitalization was 2.5 weeks. Two patients were treated in the emergency room with towel clip fixation of the chest wall as a life-saving measure, and were maintained in traction to the towel clips as definitive therapy. The other patients were immobilized with sandbags, and later treated with open thoracotomy for fixation of the chest wall. All these patients were brought to the emergency room without delay and diagnosis was established by physical examination. Recovery was uncomplicated in all but two patients: one with atelectasis of the lower lobe of the right lung and one with a drug reaction.

Two patients were seen with ruptured diaphragms, which were successfully repaired. Because this is an injury that seldom occurs alone, it is discussed in more detail in the section on compound injuries. One of the patients with a ruptured diaphragm was twenty-five years old and the other was sixty. Both were seen in the emergency room shortly after the accident, and therapy was begun immediately. In each case the repair of the diaphragm followed other measures, and became an emergency procedure only when shortness of breath occurred. Both patients were hospitalized for more than a month; their recovery was complicated by associated neurologic and orthopedic damage.

Four patients were seen with a ruptured bronchus which was repaired successfully. The average age of this group of patients was twenty-five and the average hospitalization was 3.8 weeks per patient. The diagnosis in three of these patients was established in the emergency room. The fourth patient was transferred from another hospital after the diagnosis had been established. All the patients presented with tension pneumothorax which did not respond to closed thoracotomy and massive suction. In each instance, closed thoracotomy was done initially in the emergency room, but when the patient continued to have a large air leak and the involved lung failed to expand, the patient was taken to the operating room for open thoracotomy. Primary suture of the involved bronchus with interrupted silk sutures has been uniformly successful (Fig. 1) and in only one case has there been a subsequent bronchial stricture.

Traumatic pneumonitis or intrapulmonary hematoma is seldom recognized as an isolated entity. This diagnosis must be considered with

the appearance of a mass lesion after severe injury to the chest, and complete resolution of the process may require several weeks. It was possible to find only one case in the present study. In this instance, the patient was twenty-five years old and was discharged within the first week. He remained asymptomatic and was followed up for regression of the intrapulmonary mass.

Rupture of the thoracic aorta is an injury of the utmost urgency, and rapid diagnosis and intervention are necessary. There has been one successful repair of such an injury at this hospital; the only successful repair reported in the literature to date. In this case, the patient was transferred from another hospital with a tentative diagnosis of ruptured aorta. This diagnosis was based on a rapidly progressive left hemothorax and widening mediastinum. Open thoracotomy demonstrated a huge left hemothorax and an extrapleural hematoma containing 3,000 cc of blood. After evacuation of the chest cavity, a laceration was seen on the descending thoracic aorta immediately below the ligamentum arteriosum. Repair of the laceration was impossible without first cross clamping the aorta for relief of pressure at the site of injury. The closure with No. 5-0 arterial silk was followed by reinforcement with a teflon felt patch. (Fig. 2.) The patient made an uneventful recovery and has been followed up with retrograde carotid aortography.

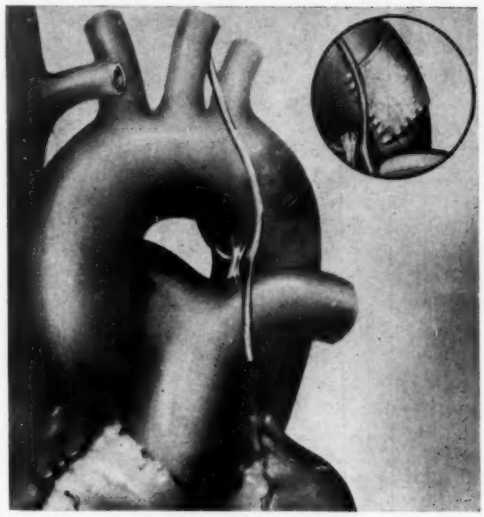

FIG. 2. Repair of laceration on descending thoracic aorta, with reinforcement of the area with a teflon felt patch.

TABLE 1

FINDINGS IN PATIENTS WHO DIED FROM INTRATHORACIC TRAUMA

Hospital No.	Age (yr.)	Multiple Rib Fractures	Shock	Internal Abdominal Injury	Orthopedic Injury	Neurologic Injury	Surgery (Thoracic)	Time of Death (after Hospitalization)	Other
512659	18	X	X	X	..	..	No	7 days	.....
627636	20	X	X	..	X	X	Yes	1 day	.....
591273	25	X	X	..	..	X	No	3 days	.....
531539X	26	X	X	..	X	X	Yes	1 day	.....
525526	29	X	X	X	X	..	Yes	9 days	.....
613554	35	X	..	..	..	..	Yes	10 days	.....
550947A	39	X	..	..	..	X	Yes	36 days	.....
514923	54	X	X	X	X	X	Yes	11 days	.....
536098A	56	X	..	X	X	X	No	8 days	Aorta rupture (not cause of death, but sustained)
514623A	63	X	X	X	X	..	Yes	Died in operating room	.....
543244X	64	X	..	..	..	X	No	8 days	Neurosurgical
590434	65	X	X	X	X	X	Yes	Died in operating room	.....
542184X	76	X	..	..	..	X	No	1 day	.....

Two patients were classified as having delayed trauma. They had been treated conservatively elsewhere for hemothorax and were admitted to this hospital because of persistent symptoms. One patient required aspiration of a hemothorax, and the other required decortication. The latter procedure caused the patient to be hospitalized for four weeks; this points out the need for more aggressive initial therapy to lessen morbidity.

Isolated injuries to the heart are rare following automobile accidents. One case has been found in which there was evidence of myocardial damage. The patient was admitted to the hospital because of fractures of the ribs and pelvis, and hemothorax. During the first week of hospitalization, a loud friction rub was heard in the precordial region. Roentgenographic examination of the chest showed enlargement of the cardiac silhouette. A pericardial tap yielded only a small amount of blood-tinged serous fluid. Electrocardiograms showed diffuse myocardial damage. The patient made a gradual but complete recovery. Both the electrocardiographic pattern and cardiac silhouette returned to normal. Patients with massive injury to the chest or changing physical signs require evaluation including serial electrocardiograms.

Thirteen patients died during their hospitalization. (Table 1.) The average age of these patients was forty-six years. Ten patients died within the first week, and two the second week. The last patient died after two months from neurologic complications. All but one of these patients had multiple rib fractures with some degree of flail chest which required fixation. All the patients also had orthopedic and/or neurologic injuries, and five had serious intra-abdominal injuries. Fifty per cent of the patients were in shock when first seen in the emergency room.

COMMENTS

In 1958, 37,000 Americans lost their lives as a result of automobile accidents. Another 1,350,000 were injured seriously. Studies have shown that the steering wheel is an important mechanism in serious automobile injuries. The intrathoracic injuries that result carry a mortality rate of approximately 20 per cent.

In the present study, the prognosis for the patient with a significant injury to the chest after an automobile accident was influenced by his age and the severity of the associated injuries. Only three of the thirteen patients who died were younger than forty. None of the patients with simple and uncomplicated trauma to the chest died. On the other hand, all the patients who died sustained multiple and severe orthopedic and/or neurologic injuries.

Simple pneumothorax occurred most often in patients in the younger age group whose elastic thoracic cavity absorbs the impact and protects them from multiple fractures and flail chest. Seventy-five per cent of the instances of pneumothorax occurred on the right side and could be attributed to the position of the steering wheel. It would be interesting to investigate the frequency of left pneumothorax in accident victims in England. It is the present policy of this clinic to treat pneumothorax of any significant degree (15 per cent or more) with immediate closed thoracotomy, using a No. 18 French catheter with multiple holes. The catheter is placed through the second anterior interspace, and underwater suction is maintained for twenty-four to forty-eight hours. If results are not obtained at the end of this time, open thoracotomy is recommended.

Three of the four cases of ruptured bronchus occurred in the right main stem bronchus. Failure of response to closed thoracotomy by immediate resolution of the pneumothorax should be grounds for suspicion of a ruptured bronchus, and open thoracotomy should be considered as an emergency procedure. As a minimal compromise, bronchoscopy should confirm the diagnosis of rupture of a main stem bronchus.

In five of thirteen patients presenting with hemothorax the diagnosis was overlooked. This presents an interesting diagnostic challenge. It appears that the major concern of most examiners is the presence of air in the chest. Moreover, air in the pleural cavity tends to collect rapidly and dramatically, and its effect seldom goes unrecognized. Pneumothorax is diagnosed by roentgenography. The diagnosis of hemothorax is somewhat more elusive. The accumulation of blood in the chest tends to be gradual and quiet but persistent. It is difficult to detect by physical examination unless massive, and the radiologic picture can be misinterpreted. An upright film is mandatory

to establish this diagnosis. The reluctance to move or disturb the accident victim, even after the initial examination, produces the non-diagnostic supine anteroposterior x-ray film of the chest. As a minimal compromise, a lateral decubitus chest film must be taken to demonstrate a blood level. Two-thirds of the patients with hemothorax had associated injuries which also tended to distract from the intrathoracic injury.

Hemopneumothorax was generally more severe and occurred in an older age group. This injury resulted from sudden stress to the inelastic lung with adhesions to the chest wall. It was often associated with complications and death regardless of the type of initial therapy. This might be attributed to the severity of the associated damage to the lung with this type of injury.

Review of the autopsy records of this hospital has shown that eighteen diagnoses of rupture of the thoracic aorta have been made at postmortem examination. Only two patients were admitted to the hospital alive and the diagnosis made at that time; one patient was treated successfully. The other patient, a thirty year old physician, died before his injury could be repaired successfully. The fact that one case has been successfully repaired should stimulate further aggressive management when a patient with injury to the chest shows evidence of a progressively widening mediastinum.

SUMMARY

The charts of over 400 patients admitted to the Ohio State University Hospital following automobile accidents have been reviewed. Eliminated from the study were those patients with primarily neurologic, orthopedic or intra-abdominal injuries, and those patients with damage to the ribs and chest wall without intrathoracic manifestations. Of the seventy-six patients remaining, the types of injury and the basis for the mortality are discussed.

The management of the specific injuries is presented.

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DISCUSSION

Rudolph J. Noer (Louisville, Ky): I was particularly interested in the authors' application of a patch type of onlay graft to the arch of the aorta. Two years ago Dr. Harold Planter reported to the Western Surgical Association on a similar graft applied to a patient with a gunshot wound of the arch of the aorta. This man is still living and well. Although the experimental work performed on dogs was successful, the animals which were repaired without grafts also did very well. There was less reaction in the adjacent tissues than Planter had believed would be the case with high velocity missiles.

W. G. Pace (closing): The problem of rupture of the aorta was presented by Dr. Raport at the Central Surgical meeting last spring. He had had the aid of General Motor's research department in developing a thesis as to the mechanism of this lesion. It was their belief that this was a transverse fiber tear involving most of the wall of the aorta. He postulated further that the aneurysms of later life which developed at that point probably represented earlier severe trauma to the chest, with weakening of the aorta wall.

We put the patch in place in our patient hoping

to prevent an aneurysm. The area covered was very fragile, and there was certainly a good bit of local aortic damage from the blow to the chest wall. We followed up the patient four months later with retrograde carotid aortograms. These showed that there was a small area of irregularity of the distal arch, and a question perhaps of a very small, early aneurysm.

This case will be published in *Surgery* in the near future and will include the x-ray films of the aorta. We plan further follow-up examinations and retrograde aortography in this patient.